# the Acid Deposition Research Program

## BIOPHYSICAL RESEARCH

### RESULTS OF THE EMISSION SOURCE SURVEYS: EMISSION INVENTORY OF SULPHUR OXIDES AND NITROGEN OXIDES IN ALBERTA


by:

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Calgary, Alberta, Canada



November, 1987

PRIME RESEARCH CONTRACTOR:

The Kananaskis Centre for Environmental Research
The University of Calgary
Calgary, Alberta, Canada


Acid Deposition Research Program

88-00584/

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## Emission Inventory

| Report Number | References |
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| ADRP-B-12-87 | Picard, D. J., and Colley, D. G., and Boyd, D. H. 1987. **Overview of the Emission Data: Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta.** Prep for the Acid Deposition Research Program by Western Research, Division of Bow Valley Resource Services Ltd., Calgary, Alberta, Canada. ISBN 0-921625-18-9 (Volume 1) ISBN 0-921625-17-0 (Set of 4) |
| ADRP-B-13-87 | Picard, D. J., and Colley, D. G., and Boyd, D. H. 1987. ***Design of the Emission Inventory: Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta.** Prep for the Acid Deposition Research Program by Western Research, Division of Bow Valley Resource Services Ltd., Calgary, Alberta, Canada. ISBN 0-921625-19-7 (Volume 2) ISBN 0-921625-17-0 (Set of 4) |
| ADRP-B-14-87 | Picard, D. J., and Colley, D. G., and Boyd, D. H. 1987. ***Emission Data Base: Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta.** Prep for the Acid Deposition Research Program by Western Research, Division of Bow Valley Resource Services Ltd., Calgary, Alberta, Canada. ISBN 0-921625-20-0 (Volume 3) ISBN 0-921625-17-0 (Set of 4) |
| ADRP-B-15-87 | Picard, D. J., and Colley, D. G., and Boyd, D. H. 1987. ***Results of the Emission Source Surveys: Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta.** Prep for the Acid Deposition Research Program by Western Research, Division of Bow Valley Resource Services Ltd., Calgary, Alberta, Canada. ISBN 0-921625-21-9 (Volume 4) ISBN 0-921625-17-0 (Set of 4) |

***Detailed data compilations, of technical interest.**

# EMISSION INVENTORY OF SULPHUR OXIDES AND NITROGEN OXIDES IN ALBERTA

## VOLUME 4
## RESULTS OF THE EMISSION SOURCE SURVEYS

by

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Acid Deposition Research Program
3860, 150-6th Avenue S.W.
Calgary, Alberta T2P 3Y7

November, 1987

This publication may be cited as:

Picard, D.J., and Colley, D.G., and Boyd, D.H. 1987.
***Results of the Emission Source Surveys: Emission Inventory of Sulphur Oxides and Nitrogen Oxides in Alberta.** Prep for the Acid Deposition Research Program by Western Research, Division of Bow Valley Resource Services Ltd., Calgary, Alberta, Canada. **ADRP-A-4-87.** 204 pp.

ISBN 0-921625-21-9 (Volume 4)

ISBN 0-921625-17-0 (Set of 4)

## EXECUTIVE SUMMARY

Air quality predictions play an important role in solving existing air pollution problems and in evaluating the potential impact of proposed emission sources. To predict air quality properly at a given location, it is necessary to identify all emission sources that will have significant impact at that location. Furthermore, the atmospheric pollutants that are emitted by these sources must be identified and quantitatively characterized. Once the air quality predictions have been made, it is desirable to have some historical air quality data for comparison. An efficient means of obtaining this information is through the use of detailed emission inventories and an inventory of air quality monitoring stations.

With specific regard to acid-forming emissions (i.e., sulphur dioxide and nitrogen oxides), it has been recognized that existing inventories for Alberta are either incomplete or do not provide sufficient detail to permit the investigation of specific regions within the province. Therefore, as part of the Alberta Government/Industry Acid Deposition Research Program (ADRP), three comprehensive inventories have been developed, namely:

- a sulphur dioxide ($SO_2$) emission inventory,
- a nitrogen oxides ($NO_x$) emission inventory, and
- an inventory of air quality monitoring stations.

The basic objectives in developing these three inventories have been:

(1) To identify all noteworthy anthropogenic sources of $SO_2$ and $NO_x$ emissions in Alberta. This includes all $SO_2$ and $NO_x$ emission sources that are licensed by the Alberta Government to operate under the Clean Air Act, sour oil batteries that emit more than 0.2 tonnes/day (t/d) of $SO_2$, and the following $NO_x$ emission sources:

- industrial engines with a maximum rated power output of greater than 100 kW,
- urban centres, and
- the major portions of high traffic highways in the province (Highways 1, 2 and 16).

Licensed industrial sources include natural gas processing facilities, oil refineries, oil sands and heavy oil recovery facilities, fertilizer and chemical plants, power generation plants, pulp and paper plants, and cement plants.

Sources were identified on the basis of 1985-86 records available from government agencies and existing inventories. Emissions were estimated based on 1984 production data. Limited verification and updating of sources occurred in 1987.

(2) To characterize each emission source, as appropriate, with respect to:

- type of emission (i.e., $NO_x$ or $SO_2$),
- geographic location (i.e., Legal Subdivision, Section, Township, and Range),
- environmental setting (surrounding vegetation, ecoregion type),
- physical characteristics (e.g., stack height and diameter),
- maximum licensed emission rate (where applicable), and
- emission characteristics (i.e., exit velocity, exit temperature, average emission rate, temporal variations and emission rate precision).

(3) To conduct a limited NOx source sampling program in order to develop Alberta-specific NOx emission factors for natural gas fueled reciprocating and turbine engines, and to assess the importance of waste gas incinerator units as NOx emission sources.

(4) To identify all air quality monitoring stations at which ambient levels of NOx and/or $SO_2$ are measured.

(5) To computerize the inventories so that information may be easily retrieved and the inventories easily updated.

The three inventories are intended to serve as a source of information that will assist investigators in estimating the average rates of NOx and $SO_2$ emission in Alberta, and the distribution of these emissions by geographic area, industry type, and environmental setting (ecoregion). The inventories will also be useful in predicting changes in emission levels by the current emission sources due to future changes in production levels (i.e., forecasting future emissions). Administrative information, including operator name, approvals and regulatory information, is also provided for each industrial source to facilitate source-specific research.

To enable use of the emissions data base in emissions forecasting and to allow prediction of emission rates from sources for which actual emission data are unavailable, emission rates for each of the sources inventoried have been estimated based on the use of emission factors. Emission factors are average values that relate the emission of NOx or $SO_2$, as appropriate, to a suitable operating parameter of the sources (generally, process production data).

The estimated emission rates presented in the emissions data base are expressed as average daily values. As such, these emission rates

have been averaged over the sum of both operating and non-operating periods (most emission sources experience some down time during the year, usually for maintenance purposes). Although estimates of typical emission rates during operating periods are not presented in the inventory, these values may be readily determined using available process production data and the presented emission factors.

The emissions data base comprises 565 sources of $SO_2$ emissions and 4025 sources of $NO_x$ emissions. In total, 1945.2 t/d of $SO_2$ and $NO_x$ emissions were inventoried, 1267.0 t/d of $SO_2$ and 678.2 t/d of $NO_x$. The petroleum industry is by far the major source, accounting for approximately 38 percent of $NO_x$ emissions and 82 percent of $SO_2$ emissions. Other important sources are electric power plants ($NO_x$ and $SO_2$ emissions), highways ($NO_x$ emissions), and urban centres ($NO_x$ emissions).

Overall, it was determined that the majority of the $SO_2$ and $NO_x$ emissions (approximately 1398.0 t/d or 71.9 percent of the total) occur in the southern half of the province where industrial activity is greatest. Although numerous sources of these pollutants were identified, the total provincial emission of $SO_2$ and $NO_x$ is dominated by a few large sources rather than many smaller sources. The ten highest emitters of $SO_2$ account for 61.2 percent of the total $SO_2$ emissions, and the ten highest emitters of $NO_x$ account for 38.5 percent of the total $NO_x$ emissions.

The developed inventories have been computerized using a microcomputer-based data management system. The system chosen for this purpose was dBase III, a popular and powerful industry-standard database package that is designed for IBM and compatible computers. To assist users who may not be familiar with dBase III, a special application program named AAESI (an acronym for Alberta Atmospheric Emission Source Inventories) has been developed.

In addition to development of the three inventories that comprised this study, there are a number of other projects that are being conducted as part of the ADRP. One of these projects is a comprehensive air quality monitoring (AQM) program, involving three AQM stations. One AQM station is for the measurement of "background" air quality of air entering Alberta and is situated in the Fortress Mountain ski area of the Kananaskis Valley in the Rocky Mountains, 70 km west of Calgary, Alberta. The remaining two AQM stations are located 40 km north of Calgary on agricultural land near Crossfield, Alberta. One of the AQM stations is located west of Crossfield to assess air quality after the air has entered the Province of Alberta and been altered by regional scale emissions. The second AQM station is located southeast of Crossfield and is influenced by emissons from many sources such as Highway 2, City of Calgary, City of Airdrie, Town of Crossfield, two mushroom factories, and several sour gas (extraction) plants. A detailed survey of the incinerator stack from the sour gas plant closest to the second AQM station was included as part of the source sampling survey program conducted.

Documentation of the developed inventories is presented in four volumes. Volume 1, Overview of the Emission Data, comprises a brief summary describing development of the inventory, a summary of emissions data by emission type, geographic region, industrial category and ecoregion, a comparison with results of previous inventories, and a summary of the air quality monitoring station inventory. Conclusions and recommendations are also presented in this volume. Detailed summary tables describing emissions by major source category, petroleum industry facility type, and source type for each geographic emission region are appended to the volume.

Volume 2, Design of the Emission Inventory, presents detailed information on the classification systems, source characterization, emission calculations, and data fields employed for each emission type. Details describing the source sampling program conducted as part of the $NO_x$ inventory and the computerization of the inventories are also presented in this volume. Furthermore, a detailed discussion of some of the major air quality monitoring networks in Alberta is included.

Volume 3, Emission Data Base, is a complete printout of the three inventories.

Volume 4, Results of the Emission Source Surveys, presents detailed results of the surveys conducted as part of the emissions inventory.

This Executive Summary is common to all volumes.

## ACKNOWLEDGEMENTS

Western Research would like to thank members of the Acid Deposition Research Program (ADRP) for the opportunity to conduct this study, and to Kananaskis Centre for Environmental Research, The University of Calgary, for the opportunity of participating as a joint venture partner in the program. The cooperation and assistance of the Kananaskis Centre for Environmental Research, the Pollution Control and Standards and Approvals Divisions of Alberta Environment, Energy Resources Conservation Board, Alberta Transportation, Alberta Municipal Affairs, Environmental Protection Service of Environment Canada, Canadian Western Natural Gas Company Ltd., Northwestern Utilities Ltd., and all companies that allowed $NO_x$ testing to be conducted at their facilities are acknowledged.

Special thanks are given to Dr. Allan H. Legge, Principal Investigator, Biophysical Aspects, ADRP, members of the ADRP Science Advisory Board, and senior staff at Western Research for their critical reviews and recommendations.

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# 1. SOURCE TESTING AT A SOUR GAS (EXTRACTION) PLANT NEAR CROSSFIELD - SUMMARY REPORT

Test Date: August 21 to 22, 1985
Test Location: NE 14-28-1 W5M
(Crossfield Area)
Tested by: R. Tamura & M. Towill

## 1.1 SUMMARY

Six stack surveys were conducted on the incinerator stack for the sulphur recovery unit at a Sour Gas (Extraction) Plant located near Crossfield. These tests were conducted over a two day period with three tests being performed each day.

During the test period plant operation was stable. As would be expected, results of the individual tests compared well with one another (i.e., generally within 10 percent). Sulphur oxides were the dominant pollutant emitted. The highest rate at which sulphur oxides were emitted was 50.534 t/d (expressed as an $SO_2$ equivalent). This is approximately 69 percent of the maximum value, 73.2 t/d, for which the plant is licensed to operate under the Clean Air Act.

Only small amounts of nitrogen oxides ($NO_x$) were emitted. The highest determined rate of $NO_x$ emission was 0.096 t/d (expressed as an $NO_2$ equivalent).

## 1.2 INTRODUCTION

Under the auspices of the Alberta Government/Industry Acid Deposition Research Program (ADRP), three comprehensive inventories are being developed, namely,

- a sulphur dioxide ($SO_2$) emission inventory,
- a nitrogen oxides ($NO_x$) emission inventory, and
- an inventory of air quality monitoring stations.

In addition to development of the inventories, a number of other projects are being conducted as part of ADRP. One of these projects is a comprehensive air quality monitoring (AQM) program involving three AQM stations. One AQM station is for the measurement of "background" air quality of air entering Alberta and is situated in the Rocky Mountains at 2103 m in the Fortress Mountain ski area in the Kananaskis Valley, 70 km west of Calgary, Alberta. The remaining two AQM stations are located 40 km north of Calgary on agricultural land near Crossfield, Alberta. One of the AQM stations is located west of Crossfield and is described as a "regional" location to assess air quality after the air has entered the Province of Alberta and been altered by regional scale emissions. The second AQM station is located southeast of Crossfield and is influenced by emissions from many sources such as Highway 2, City of Calgary, City of Airdrie, Town of Crossfield, two mushroom factories, and several sour gas (extraction) plants. Six stack surveys were conducted on the incinerator stack at the gas plant closest to the second AQM station. This testing was conducted during the period August 21 to 22, 1985.

## 1.3 PROCEDURE

The six stack surveys were conducted over a two day period, during which the plant was under normal load and stable operation. Each survey consisted of:

- determination of stack gas velocity and volumetric flow rate,
- determination of gas composition and molecular weight,
- determination of moisture content,
- determination of $SO_x$, and
- determination of $NO_x$.

Each of these determinations, with the exception of that for $SO_x$, was conducted in accordance with the Alberta Stack Sampling Code (Alberta Environment 1976).

$SO_x$ emissions (i.e., the sum of $SO_2$ and $SO_3$ emissions) were determined using a modification of Alberta Environment (AE) (1976)Method 5 for determination of $SO_2$ emissions. AE Method 5 requires that a distinction be made between $SO_2$ and $SO_3$ emissions. This is achieved through the use of two quantitative absorption processes - first the sample is reacted with isopropanol for preferential removal of the $SO_3$ and then it is reacted with an aqueous $H_2O_2$ solution for removal of the $SO_2$. Since a distinction between $SO_2$ and $SO_3$ emission is not required here, the isopropanol solution was omitted and the $SO_2$ and $SO_3$ reacted simultaneously using the $H_2O_2$ solution to obtain total $SO_x$. The result of the modification is a simplified method for determination of $SO_x$ emissions. This modified method is accepted by Alberta Environment for use in routine compliance tests.

## 1.4 RESULTS AND DISCUSSION

Computer output for the specified determinations are appended in Section 1.6. A summary of these results is presented in Table 1. Overall flue gas composition during each test is presented in Table 2. In viewing Tables 1 and 2 it can be seen that there is very good agreement among the tests. The deviation between corresponding data is generally less than 10 percent.

As would be expected, sulphur oxides were the primary pollutant emitted by the incinerator stack. Values for this are shown in Table 1 and have been expressed as both equivalent $SO_2$ and S emissions. The average determined rate of $SO_2$ emission was 49.4 t/d. This is approximately 67.5 percent of the maximum value,

Table 1. Summary of source emission test results.

A.D.R.P. August 21-22, 1985
Crossfield File Number 5390-85-1

| Parameter | Test One 85/08/21 | Test Two 85/08/21 | Test Three 85/08/21 | Test Four 85/08/22 | Test Five 85/08/22 | Test Six 85/08/22 |
|---|---|---|---|---|---|---|
| Average Gas Temperature - °C | 421 | 420 | 434 | 426 | 432 | 430 |
| Average Gas Velocity** - m/s | 15.983 | 16.387 | 16.406 | 16.738 | 16.730 | 16.905 |
| Total Stream Flow Rate* | | | | | | |
| - $m^3/s$ | 62.184 | 63.805 | 62.632 | 64.673 | 64.103 | 64.980 |
| - kmols/h | 9269.965 | 9511.598 | 9336.730 | 9640.906 | 9555.965 | 9686.703 |
| Water Content - mole % | 20.63 | 21.07 | 21.37 | 20.51 | 21.34 | 20.97 |
| Oxides of Sulphur | | | | | | |
| Wet Concentration - mole % | 0.3372 | 0.3276 | 0.3460 | 0.3365 | 0.3401 | 0.3389 |
| Flow Rate* - $m^3/s$ | 0.210 | 0.209 | 0.217 | 0.218 | 0.218 | 0.220 |
| Emission as $SO_2$ - t/d | 48.117 | 47.966 | 49.726 | 49.933 | 50.020 | 50.534 |
| as S - t/d | 24.059 | 23.983 | 24.863 | 24.966 | 25.010 | 25.267 |
| Oxides of Nitrogen | | | | | | |
| Wet Concentration - ppm | 4 | 6 | 0*** | 9 | 4 | 0*** |
| Flow Rate* - $m^3/s$ | 0.0002 | 0.0004 | - | 0.0006 | 0.0003 | - |
| Emission as $NO_2$ - t/d | 0.041 | 0.063 | - | 0.096 | 0.042 | - |
| Mass Ratio of $NO_X/SO_2$ Emissions | 0.00085 | 0.00131 | - | 0.00192 | 0.00084 | - |

* At 21°C and 101.325 kPa, Wet Flow

** Due to the presence of other sampling equipment, a full diameter could not be traversed when measuring the stack velocity. Therefore, two half diameters at 90° were measured.

*** The occurrence of zero $NO_X$ readings for these tests is attributed to leakage problems with the $NO_X$ sample containers.

Table 2. Total flue gas composition - mole percent.

A.D.R.P.
Crossfield

August 21-22, 1985
File Number 5390-85-1

| Parameter | Test One 85/08/21 | Test Two 85/08/21 | Test Three 85/08/21 | Test Four 85/02/22 | Test Five 85/08/22 | Test Six 85/08/22 |
|---|---|---|---|---|---|---|
| Hydrogen ($H_2$) | 0.5635 | 0.5350 | 0.5149 | 0.5804 | 0.5540 | 0.5534 |
| Argon (Ar) | 0.7831 | 0.7810 | 0.7759 | 0.7849 | 0.7785 | 0.7815 |
| Oxygen ($O_2$) | 5.6704 | 5.4726 | 5.8125 | 5.4574 | 5.2220 | 5.2886 |
| Nitrogen ($N_2$) | 65.4783 | 65.2777 | 64.8782 | 65.6281 | 65.0975 | 65.3493 |
| Methane ($C_1$) | 0.1846 | 0.1733 | 0.1803 | 0.1772 | 0.1787 | 0.1729 |
| Carbon Monoxide (CO) | 0.4632 | 0.4664 | 0.4319 | 0.5063 | 0.4879 | 0.4872 |
| Carbon Dioxide ($CO_2$) | 5.8632 | 5.8494 | 5.6652 | 5.9930 | 5.9781 | 6.0316 |
| Ethane ($C_2$) | 0.0036 | 0.0034 | 0.0038 | 0.0040 | 0.0037 | 0.0041 |
| Ethylene ($C_2$=) | 0.0019 | 0.0014 | 0.0013 | 0.0014 | 0.0011 | 0.0022 |
| Hydrogen Sulphide ($H_2S$) | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. |
| Carbonyl Sulphide (COS) | 0.0132 | 0.0159 | 0.0128 | 0.0130 | 0.0120 | 0.0129 |
| Sulphur Dioxide ($SO_2$) | 0.3372 | 0.3441 | 0.3460 | 0.3365 | 0.3401 | 0.3389 |
| Carbon Disulphide ($CS_2$) | 0.0058 | 0.0078 | 0.0060 | 0.0057 | 0.0052 | 0.0056 |
| Propane+ ($C_3$+) | 0.0016 | 0.0014 | 0.0012 | 0.0012 | 0.0008 | 0.0018 |
| Nitrogen Dioxide ($NO_2$) | 0.0004 | 0.0006 | N.D. | 0.0009 | 0.0004 | N.D. |
| Water ($H_2O$) | 20.63 | 21.07 | 21.37 | 20.51 | 21.34 | 20.97 |
| Total | 100.0000 | 100.0000 | 100.0000 | 100.0000 | 100.0000 | 100.0000 |

N.D. - Analyzed for but not detected.

73.2 t/d, for which the plant is licensed to operate under the Clean Air Act.

Only small amounts of nitrogen oxides ($NO_x$) were emitted, as indicated in Table 1. The average determined $NO_x$ emission rate was 0.061 t/d.

The average mass ratio of $NO_x$ to $SO_2$ emitted from the stack was 0.00123. Therefore, in comparison to $SO_2$ emissions, the $NO_x$ emissions from this source are insignificant.

## 1.5 CONCLUSIONS

In terms of atmospheric pollutants, the incinerator stack at the Crossfield plant is primarily a source of oxides of sulphur emissions. The average determined rate at which oxides of sulphur was emitted was 49.4 t/d (expressed as an $SO_2$ equivalent). Only small amounts of $NO_x$ were emitted. The average determined $NO_x$ emission rate was 0.061 t/d (expressed as $NO_2$ equivalent).

## 1.6 COMPUTER OUTPUT

This section contains the computer output for the primary determinations (i.e., stack gas velocity, volumetric flow rate, gas composition, molecular weight, moisture content, $SO_2$ concentration and $NO_x$ concentration), graphs showing the velocity profile determined for each traverse, and summaries of the field and laboratory data.

ADRP CROSSFIELD INCINERATOR STACK

EMISSION CALCULATIONS

TEST NUMBER 1 PAGE 1 DATE AUGUST 21,1985

| | |
|---|---|
| LOCATION OF SAMPLING POINT | 147 FOOT LEVEL |
| INSIDE DIAMETER OF STACK AT SAMPLING POINT | 3.65 METERS |
| INSIDE DIAMETER OF STACK AT TOP | 3.65 METERS |
| BAROMETRIC PRESSURE | 670.56 MM. HG |
| AMBIENT TEMPERATURE | 10. DEG.C |

CARBON DIOXIDE ANALYSIS
GAS CHROMATOGRAPHY 7.39 PERCENT-DRY BASIS
OXYGEN ANALYSIS
GAS CHROMATOGRAPHY 7.15 PERCENT-DRY BASIS

AVERAGE COMPOSITION OF FLUE GAS

| | DRY BASIS PERCENT | WET BASIS PERCENT |
|---|---|---|
| O2 | 7.15 | 5.65 |
| CO2 | 7.39 | 5.84 |
| N2 * | 85.46 | 67.54 |
| H2O | | 20.63 |
| SO2 | | 0.34 |

* BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00) 0.940

SULPHUR DIOXIDE ANALYSIS

| | | |
|---|---|---|
| GAS SAMPLE METERED | 6.38 | CU.FT. |
| GAS SAMPLE TEMPERATURE | 28. | DEG.C |
| VACUUM AT METER | 0.0 | MM.HG. |
| VACUUM AT CONDENSER | 38.10 | MM.HG. |
| VOLUME OF WATER COLLECTED | 29.00 | CC. |
| VOLUME OF BA(CLO4)2 USED | 556.50 | CC. |
| NORMALITY OF BA(CLO4)2 | 0.10 | N. |
| VAP.PRES.OF H2O-IMPINGER TEMP. | 0.28 | IN. OF HG. |
| AVERAGE SO2 CONCENTRATION | 0.3372 | PERCENT-WET BASIS |

TOTAL VOL OF GAS SAMPLED 8.07 CU.FT. (METER CONDITIONS)

ADRP CROSSFIELD INCINERATOR STACK

EMISSION CALCULATIONS

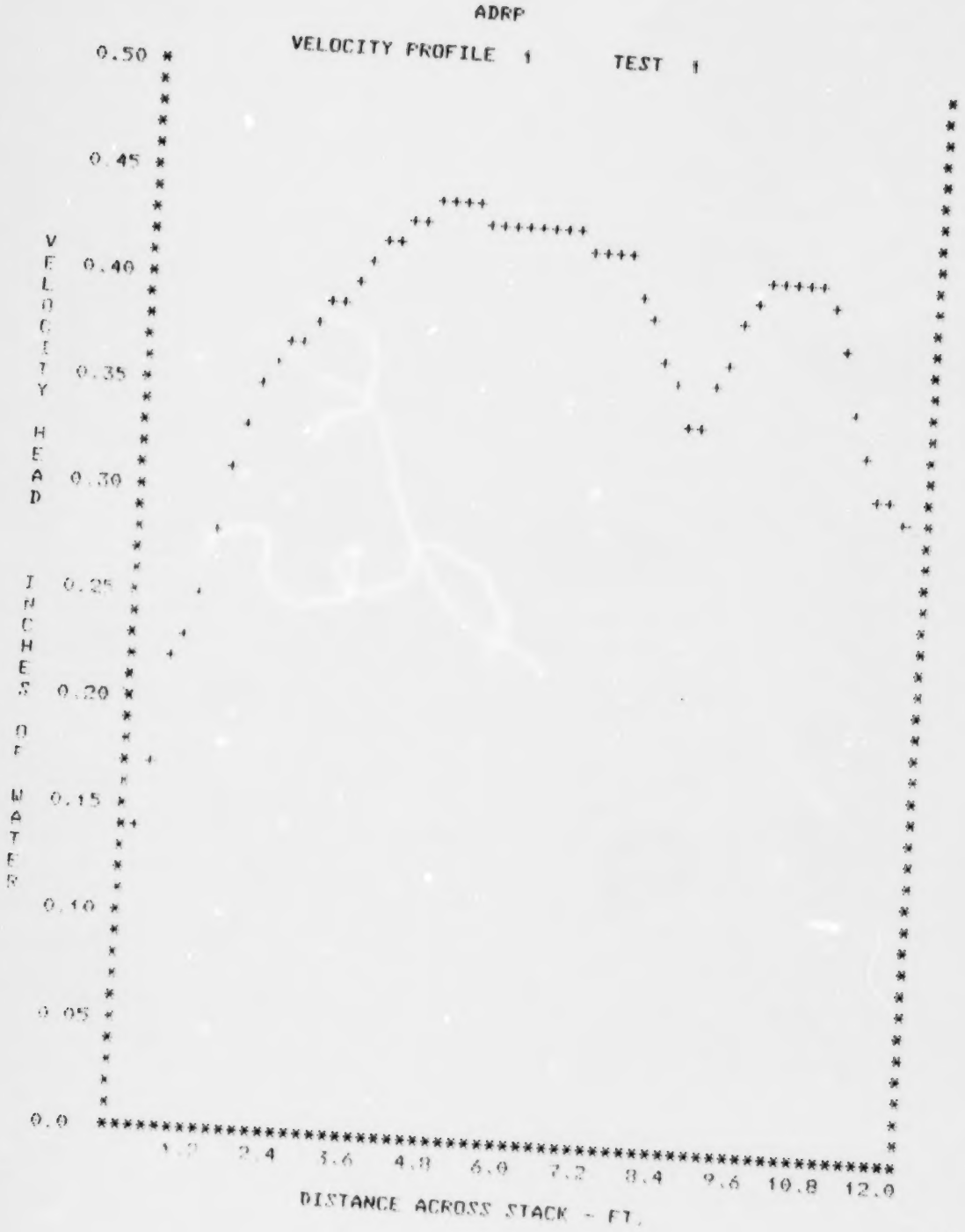
TEST NUMBER 1 PAGE 2 DATE AUGUST 21.1985

FLUE GAS FLOW RATE

| SECTOR | PROBE TIP FROM WALL-FT. | VELOCITY HEAD - IN. H2O TRAVERSE NUMBER 1 |
|---|---|---|
| 1 | 0.190 | 0.140 |
| 2 | 0.590 | 0.200 |
| 3 | 1.022 | 0.250 |
| 4 | 1.495 | 0.320 |
| 5 | 2.024 | 0.360 |
| 6 | 2.637 | 0.380 |
| 7 | 3.390 | 0.410 |
| 8 | 4.485 | 0.440 |
| 8 | 4.485 | 0.420 |
| 7 | 3.390 | 0.330 |
| 6 | 2.637 | 0.400 |
| 5 | 2.024 | 0.410 |
| 4 | 1.495 | 0.410 |
| 3 | 1.022 | 0.370 |
| 2 | 0.590 | 0.310 |
| 1 | 0.190 | 0.300 |
| AV. SQ. ROOT | | 0.578 |

| | |
|---|---|
| AVERAGE STATIC PRESSURE | -3.30 CM. H20 |
| AVERAGE FLUE GAS TEMPERATURE | 421. DEG.C |
| PITOT TUBE CALIBRATION FACTOR | 0.804 |
| OVERALL AVERAGE SQUARE ROOT | 0.578 |
| AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL | 15.983 M/SEC - MEAS. |
| STACK TOP | 15.983 M/SEC - CALC. |
| TOTAL FLUE GAS FLOW RATE | 62.184 M3/S* |
| | 9269.965 KMOLS/HR |
| SULPHUR DIOXIDE EMISSION RATE | 0.210 M3/S* |
| | 48.117 TONNE/D SO2 |
| | 24.059 TONNE/D SULPHUR |

* VOLUMES EXPRESSED AT 21.1 C AND 760 MM HG


ADRP
VELOCITY PROFILE 1 TEST 1
VELOCITY HEAD INCHES OF WATER
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.0
1.2
2.4
3.6
4.8
6.0
7.2
8.4
9.6
10.8
12.0
DISTANCE ACROSS STACK - FT.

ADRP CROSSFIELD INCINERATOR STACK

EMISSION CALCULATIONS

TEST NUMBER 2 PAGE 1 DATE AUGUST 21,1985

| | |
|---|---|
| LOCATION OF SAMPLING POINT | 147 FOOT LEVEL |
| INSIDE DIAMETER OF STACK AT SAMPLING POINT | 3.65 METERS |
| INSIDE DIAMETER OF STACK AT TOP | 3.65 METERS |
| BAROMETRIC PRESSURE | 670.56 MM. HG |
| AMBIENT TEMPERATURE | 10. DEG.C |

CARBON DIOXIDE ANALYSIS
GAS CHROMATOGRAPHY 7.42 PERCENT-DRY BASIS

OXYGEN ANALYSIS
GAS CHROMATOGRAPHY 6.94 PERCENT-DRY BASIS

AVERAGE COMPOSITION OF FLUE GAS

| | DRY BASIS PERCENT | WET BASIS PERCENT |
|---|---|---|
| O2 | 6.94 | 5.46 |
| CO2 | 7.42 | 5.83 |
| N2 * | 85.64 | 67.32 |
| H2O | | 21.07 |
| SO2 | | 0.33 |

* BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00) 0.938

SULPHUR DIOXIDE ANALYSIS

| | |
|---|---|
| GAS SAMPLE METERED | 12.81 CU.FT. |
| GAS SAMPLE TEMPERATURE | 38. DEG.C |
| VACUUM AT METER | 0.0 MM.HG. |
| VACUUM AT CONDENSER | 50.80 MM.HG. |
| VOLUME OF WATER COLLECTED | 58.00 CC. |
| VOLUME OF BA(CLO4)2 USED | 1058.00 CC. |
| NORMALITY OF BA(CLO4)2 | 0.10 N. |
| VAP.PRES.OF H2O-IMPINGER TEMP. | 0.28 IN. OF HG. |
| AVERAGE SO2 CONCENTRATION | 0.3276 PERCENT-WET BASIS |

TOTAL VOL OF GAS SAMPLED 16.30 CU.FT. (METER CONDITIONS)

ADRP CROSSFIELD INCINERATOR STACK

EMISSION CALCULATIONS

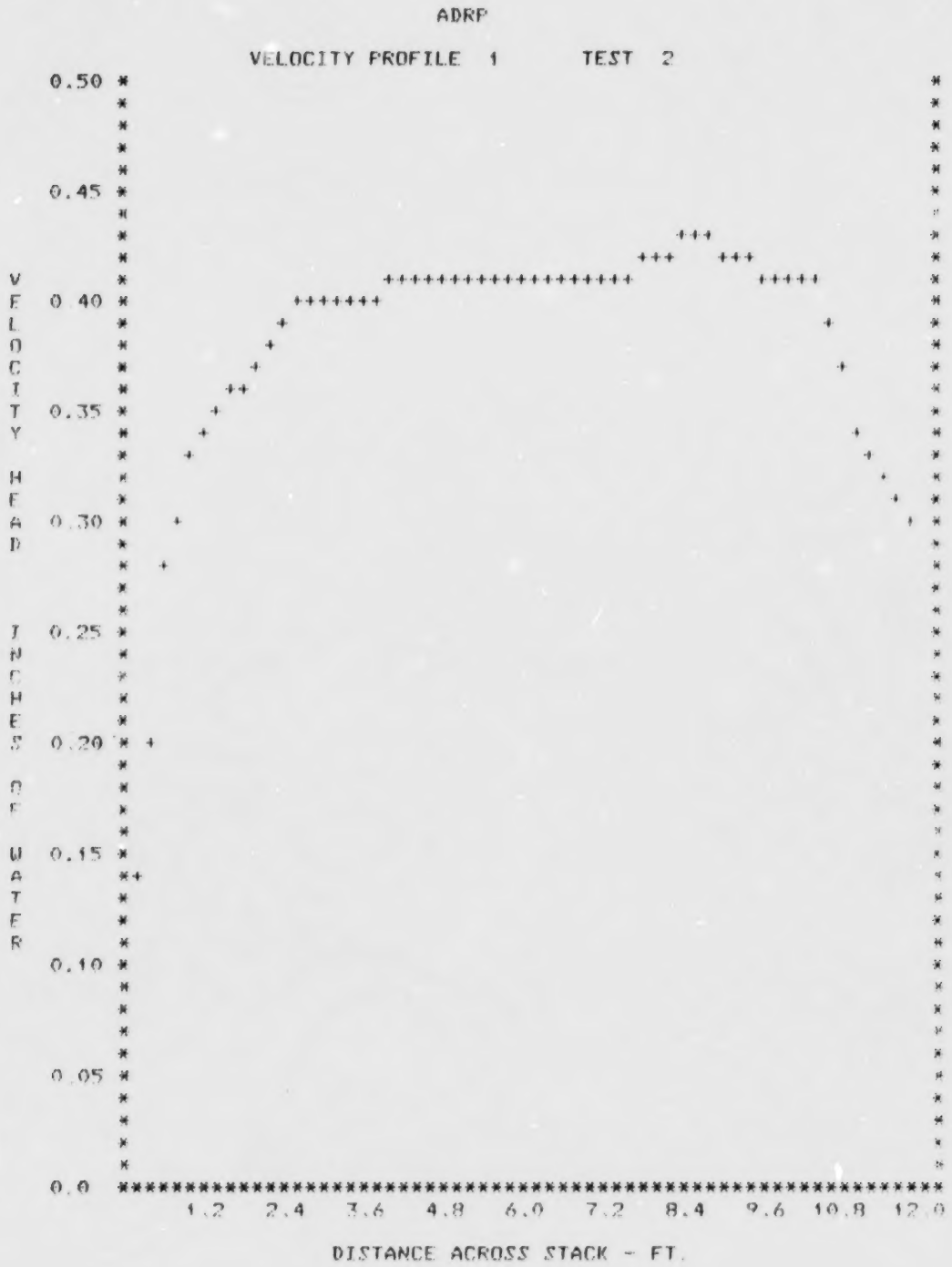
TEST NUMBER 2 PAGE 2 DATE AUGUST 21,1985

FLUE GAS FLOW RATE

| SECTOR | PROBE TIP FROM WALL-FT. | VELOCITY HEAD - IN. H20 TRAVERSE NUMBER 1 |
|---|---|---|
| 1 | 0.190 | 0.140 |
| 2 | 0.590 | 0.250 |
| 3 | 1.022 | 0.330 |
| 4 | 1.495 | 0.350 |
| 5 | 2.024 | 0.370 |
| 6 | 2.637 | 0.400 |
| 7 | 3.390 | 0.400 |
| 8 | 4.485 | 0.410 |
| 8 | 4.485 | 0.410 |
| 7 | 3.390 | 0.430 |
| 6 | 2.637 | 0.420 |
| 5 | 2.024 | 0.410 |
| 4 | 1.495 | 0.410 |
| 3 | 1.022 | 0.350 |
| 2 | 0.590 | 0.320 |
| 1 | 0.190 | 0.300 |
| AV. SQ. ROOT | | 0.593 |

| | |
|---|---|
| AVERAGE STATIC PRESSURE | -3.30 CM. H20 |
| AVERAGE FLUE GAS TEMPERATURE | 420. DEG.C |
| PITOT TUBE CALIBRATION FACTOR | 0.804 |
| OVERALL AVERAGE SQUARE ROOT | 0.593 |
| AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL | 16.387 M/SEC - MEAS. |
| STACK TOP | 16.387 M/SEC - CALC. |
| TOTAL FLUE GAS FLOW RATE | 63.805 M3/S* |
| | 9511.598 KMOLS/HR |
| SULPHUR DIOXIDE EMISSION RATE | 0.209 M3/S* |
| | 47.966 TONNE/D SO2 |
| | 23.983 TONNE/D SULPHUR |

* VOLUMES EXPRESSED AT 21.1 C AND 760 MM HG


ADRP
VELOCITY PROFILE 1 TEST 2
VELOCITY HEAD INCHES OF WATER
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.0
1.2
2.4
3.6
4.8
6.0
7.2
8.4
9.6
10.8
12.0
DISTANCE ACROSS STACK - FT.

ADRP CROSSFIELD INCINERATOR STACK

EMISSION CALCULATIONS

TEST NUMBER 3 PAGE 1 DATE AUGUST 21,1985

| | |
|---|---|
| LOCATION OF SAMPLING POINT | 147 FOOT LEVEL |
| INSIDE DIAMETER OF STACK AT SAMPLING POINT | 3.65 METERS |
| INSIDE DIAMETER OF STACK AT TOP | 3.65 METERS |
| BAROMETRIC PRESSURE | 670.56 MM. HG |
| AMBIENT TEMPERATURE | 10. DEG.C |

CARBON DIOXIDE ANALYSIS
GAS CHROMATOGRAPHY 7.21 PERCENT-DRY BASIS
OXYGEN ANALYSIS
GAS CHROMATOGRAPHY 7.40 PERCENT-DRY BASIS

AVERAGE COMPOSITION OF FLUE GAS

| | DRY BASIS PERCENT | WET BASIS PERCENT |
|---|---|---|
| O2 | 7.40 | 5.79 |
| CO2 | 7.21 | 5.64 |
| N2 * | 85.39 | 66.85 |
| H2O | | 21.37 |
| SO2 | | 0.35 |

* BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00) 0.937

SULPHUR DIOXIDE ANALYSIS

| | | |
|---|---|---|
| GAS SAMPLE METERED | 12.19 | CU.FT. |
| GAS SAMPLE TEMPERATURE | 39. | DEG.C |
| VACUUM AT METER | 0.0 | MM.HG. |
| VACUUM AT CONDENSER | 50.80 | MM.HG. |
| VOLUME OF WATER COLLECTED | 56.00 | CC. |
| VOLUME OF BA(CLO4)2 USED | 1063.60 | CC. |
| NORMALITY OF BA(CLO4)2 | 0.10 | N. |
| VAP.PRES.OF H2O-IMPINGER TEMP. | 0.28 | IN. OF HG. |
| AVERAGE SO2 CONCENTRATION | 0.3460 | PERCENT-WET BASIS |
| TOTAL VOL OF GAS SAMPLED | 15.57 | CU.FT. (METER CONDITIONS) |

ADRP CROSSFIELD INCINERATOR STACK

EMISSION CALCULATIONS

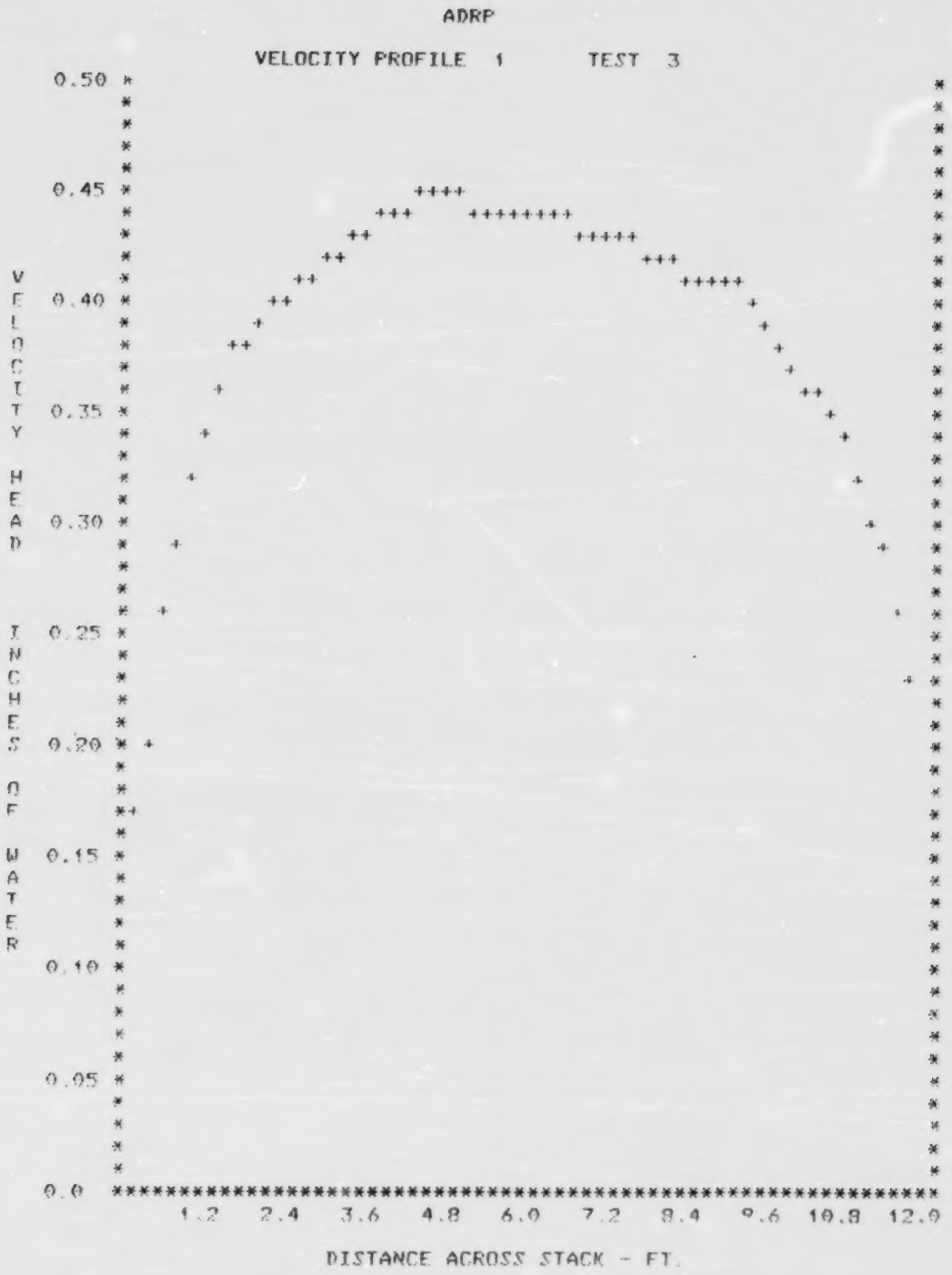
TEST NUMBER 3 PAGE 2 DATE AUGUST 21.1985

FLUE GAS FLOW RATE

| SECTOR | PROBE TIP FROM WALL-FT. | VELOCITY HEAD - IN. H20 TRAVERSE NUMBER 1 |
|---|---|---|
| 1 | 0.190 | 0.170 |
| 2 | 0.590 | 0.230 |
| 3 | 1.022 | 0.320 |
| 4 | 1.495 | 0.370 |
| 5 | 2.024 | 0.390 |
| 6 | 2.637 | 0.410 |
| 7 | 3.390 | 0.430 |
| 8 | 4.485 | 0.450 |
| 8 | 4.485 | 0.430 |
| 7 | 3.390 | 0.410 |
| 6 | 2.637 | 0.410 |
| 5 | 2.024 | 0.370 |
| 4 | 1.495 | 0.360 |
| 3 | 1.022 | 0.330 |
| 2 | 0.590 | 0.290 |
| 1 | 0.190 | 0.230 |
| AV. SQ. ROOT | | 0.587 |

| | |
|---|---|
| AVERAGE STATIC PRESSURE | -3.30 CM. H20 |
| AVERAGE FLUE GAS TEMPERATURE | 434. DEG.C |
| PITOT TUBE CALIBRATION FACTOR | 0.804 |
| OVERALL AVERAGE SQUARE ROOT | 0.587 |
| AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL | 16.406 M/SEC - MEAS. |
| STACK TOP | 16.406 M/SEC - CALC. |
| TOTAL FLUE GAS FLOW RATE | 62.632 M3/S* |
| | 9336.730 KMOLS/HR |
| SULPHUR DIOXIDE EMISSION RATE | 0.217 M3/S* |
| | 49.726 TONNE/D SO2 |
| | 24.863 TONNE/D SULPHUR |

* VOLUMES EXPRESSED AT 21.1 C AND 760 MM HG


ADRP
VELOCITY PROFILE 1 TEST 3
VELOCITY HEAD INCHES OF WATER
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.0
1.2
2.4
3.6
4.8
6.0
7.2
8.4
9.6
10.8
12.0
DISTANCE ACROSS STACK - FT.

ADRP CROSSFIELD INCINERATOR STACK

EMISSION CALCULATIONS

TEST NUMBER 4 PAGE 1 DATE AUGUST 22,1985

| | |
|---|---|
| LOCATION OF SAMPLING POINT | 147 FOOT LEVEL |
| INSIDE DIAMETER OF STACK AT SAMPLING POINT | 3.65 METERS |
| INSIDE DIAMETER OF STACK AT TOP | 3.65 METERS |
| BAROMETRIC PRESSURE | 671.32 MM. HG |
| AMBIENT TEMPERATURE | 24. DEG.C |

CARBON DIOXIDE ANALYSIS
GAS CHROMATOGRAPHY 7.55 PERCENT-DRY BASIS
OXYGEN ANALYSIS
GAS CHROMATOGRAPHY 6.87 PERCENT-DRY BASIS

AVERAGE COMPOSITION OF FLUE GAS

| | DRY BASIS PERCENT | WET BASIS PERCENT |
|---|---|---|
| O2 | 6.87 | 5.44 |
| CO2 | 7.55 | 5.98 |
| N2 * | 85.58 | 67.74 |
| H2O | | 20.51 |
| SO2 | | 0.34 |

* BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00) 0.941

SULPHUR DIOXIDE ANALYSIS

| | | |
|---|---|---|
| GAS SAMPLE METERED | 13.70 | CU.FT. |
| GAS SAMPLE TEMPERATURE | 46. | DEG.C |
| VACUUM AT METER | 0.0 | MM.HG. |
| VACUUM AT CONDENSER | 50.80 | MM.HG. |
| VOLUME OF WATER COLLECTED | 58.00 | CC. |
| VOLUME OF BA(CLO4)2 USED | 1124.20 | CC. |
| NORMALITY OF BA(CLO4)2 | 0.10 | N. |
| VAP.PRES.OF H2O-IMPINGER TEMP. | 0.31 | IN. OF HG. |
| AVERAGE SO2 CONCENTRATION | 0.3365 | PERCENT-WET BASIS |

TOTAL VOL OF GAS SAMPLED 17.31 CU.FT. (METER CONDITIONS)

ADRP CROSSFIELD INCINERATOR STACK

EMISSION CALCULATIONS

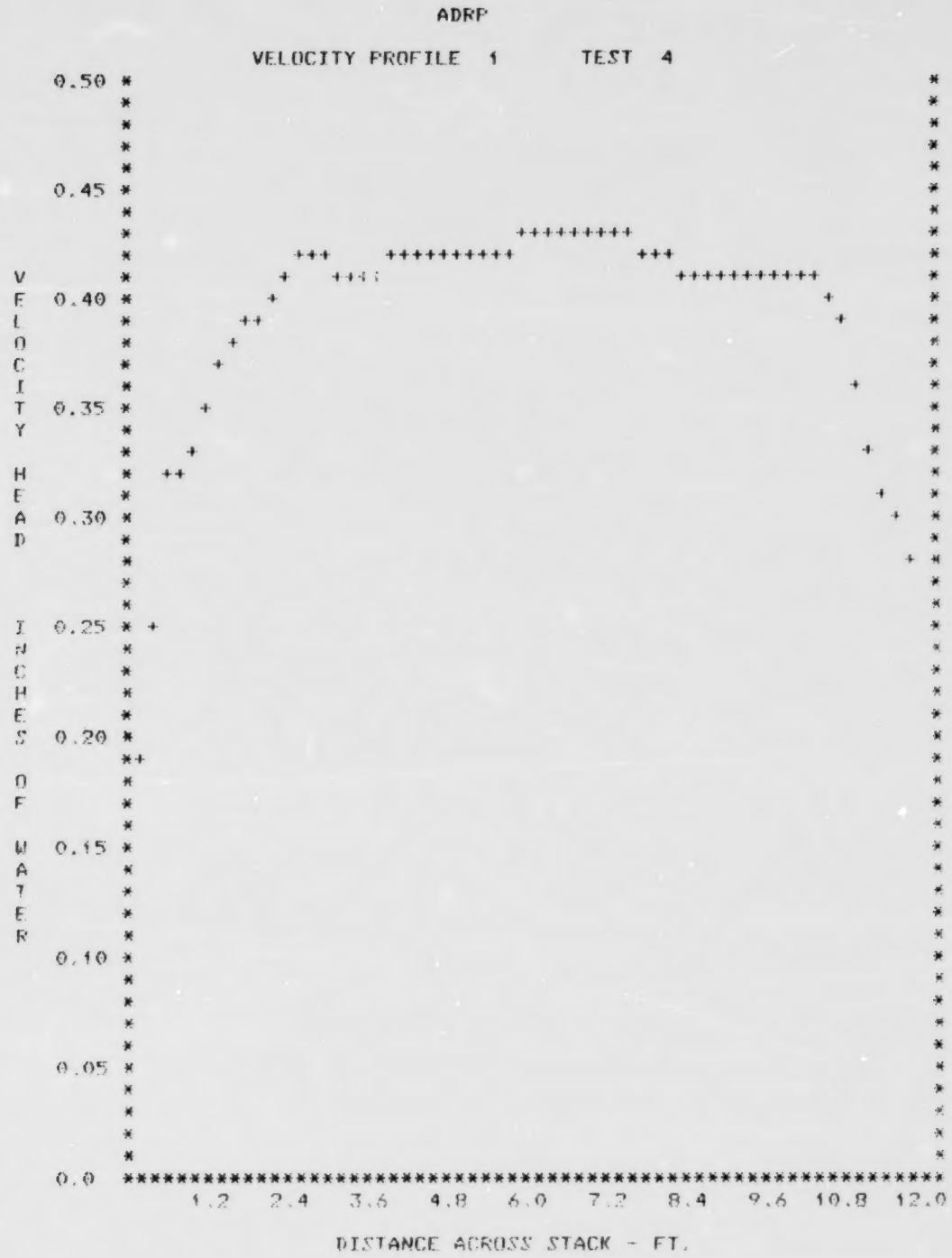
TEST NUMBER 4 PAGE 2 DATE AUGUST 22,1985

FLUE GAS FLOW RATE

| SECTOR | PROBE TIP FROM WALL-FT. | VELOCITY HEAD - IN. H2O TRAVERSE NUMBER 1 |
|---|---|---|
| 1 | 0.190 | 0.190 |
| 2 | 0.590 | 0.310 |
| 3 | 1.022 | 0.330 |
| 4 | 1.495 | 0.380 |
| 5 | 2.024 | 0.390 |
| 6 | 2.637 | 0.420 |
| 7 | 3.390 | 0.410 |
| 8 | 4.485 | 0.420 |
| 8 | 4.485 | 0.430 |
| 7 | 3.390 | 0.410 |
| 6 | 2.637 | 0.410 |
| 5 | 2.024 | 0.410 |
| 4 | 1.495 | 0.410 |
| 3 | 1.022 | 0.380 |
| 2 | 0.590 | 0.310 |
| 1 | 0.190 | 0.280 |
| AV. SQ. ROOT | | 0.604 |

| | |
|---|---|
| AVERAGE STATIC PRESSURE | -3.56 CM. H2O |
| AVERAGE FLUE GAS TEMPERATURE | 426. DEG.C |
| PITOT TUBE CALIBRATION FACTOR | 0.804 |
| OVERALL AVERAGE SQUARE ROOT | 0.604 |
| AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL | 16.738 M/SEC - MEAS. |
| STACK TOP | 16.738 M/SEC - CALC. |
| TOTAL FLUE GAS FLOW RATE | 64.673 M3/S* |
| | 9640.906 KMOLS/HR |
| SULPHUR DIOXIDE EMISSION RATE | 0.218 M3/S* |
| | 49.933 TONNE/D SO2 |
| | 24.966 TONNE/D SULPHUR |

-* VOLUMES EXPRESSED AT 21.1 C AND 760 MM HG


ADRP
VELOCITY PROFILE 1 TEST 4
VELOCITY HEAD INCHES OF WATER
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.0
1.2 2.4 3.6 4.8 6.0 7.2 8.4 9.6 10.8 12.0
DISTANCE ACROSS STACK - FT.

ADRP CROSSFIELD INCINERATOR STACK

EMISSION CALCULATIONS

TEST NUMBER 5 PAGE 1 DATE AUGUST 22,1985

| | |
|---|---|
| LOCATION OF SAMPLING POINT | 147 FOOT LEVEL |
| INSIDE DIAMETER OF STACK AT SAMPLING POINT | 3.65 METERS |
| INSIDE DIAMETER OF STACK AT TOP | 3.65 METERS |
| BAROMETRIC PRESSURE | 671.32 MM. HG |
| AMBIENT TEMPERATURE | 24. DEG.C |

CARBON DIOXIDE ANALYSIS
GAS CHROMATOGRAPHY 7.61 PERCENT-DRY BASIS
OXYGEN ANALYSIS
GAS CHROMATOGRAPHY 6.65 PERCENT-DRY BASIS

AVERAGE COMPOSITION OF FLUE GAS

| | DRY BASIS PERCENT | WET BASIS PERCENT |
|---|---|---|
| O2 | 6.65 | 5.21 |
| CO2 | 7.61 | 5.96 |
| N2 * | 85.74 | 67.16 |
| H2O | | 21.34 |
| SO2 | | 0.34 |

* BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00) 0.938

SULPHUR DIOXIDE ANALYSIS

| | |
|---|---|
| GAS SAMPLE METERED | 13.52 CU.FT. |
| GAS SAMPLE TEMPERATURE | 49. DEG.C |
| VACUUM AT METER | 0.0 MM.HG. |
| VACUUM AT CONDENSER | 50.80 MM.HG. |
| VOLUME OF WATER COLLECTED | 60.00 CC. |
| VOLUME OF BA(CLO4)2 USED | 1122.80 CC. |
| NORMALITY OF BA(CLO4)2 | 0.10 N |
| VAP.PRES.OF H2O-IMPINGER TEMP. | 0.29 IN. OF HG. |
| AVERAGE SO2 CONCENTRATION | 0.3401 PERCENT-WET BASIS |

TOTAL VOL OF GAS SAMPLED 17.26 CU.FT. (METER CONDITIONS)

ADRP CROSSFIELD INCINERATOR STACK

EMISSION CALCULATIONS

TEST NUMBER 5 PAGE 2 DATE AUGUST 22,1985

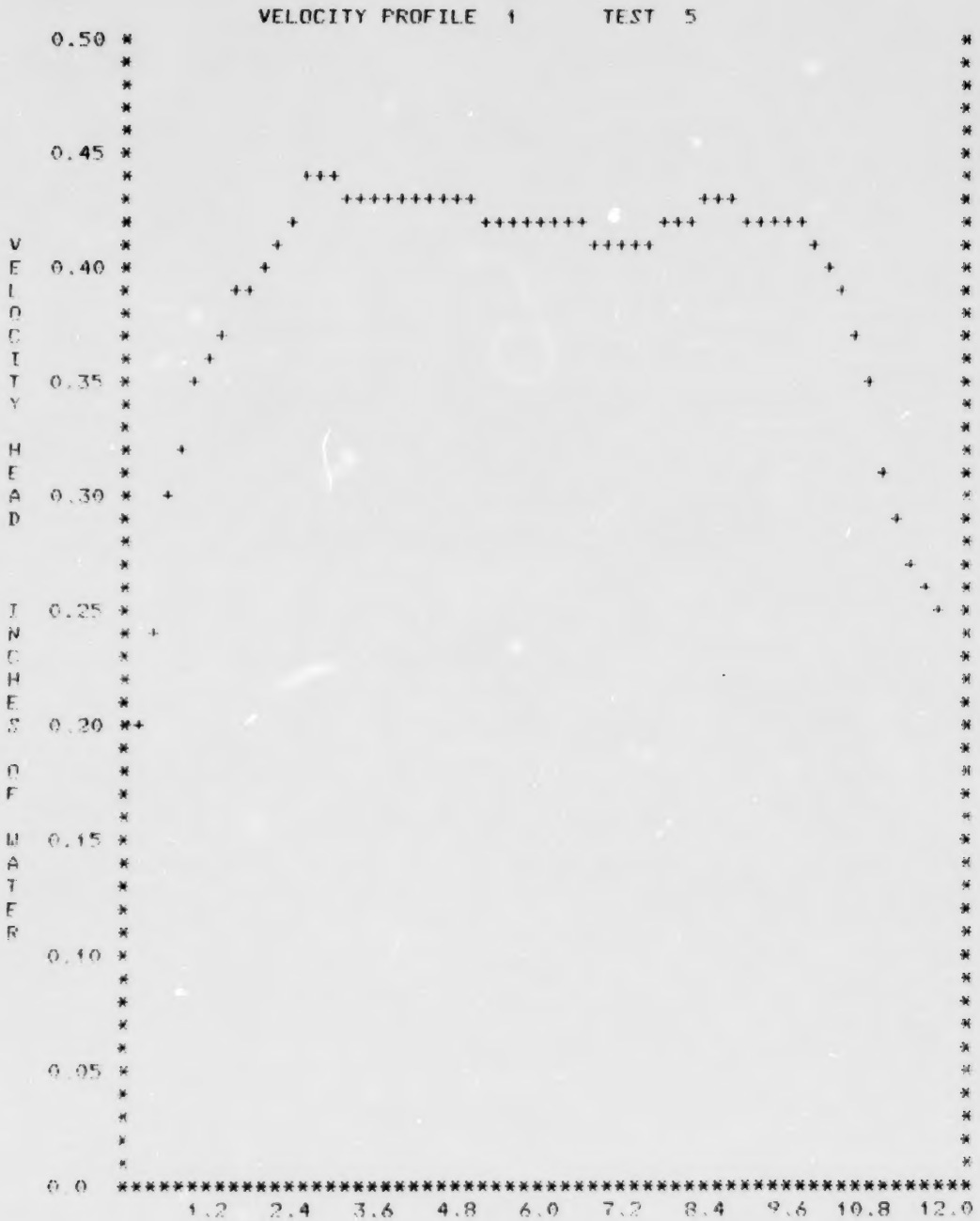
FLUE GAS FLOW RATE

| SECTOR | PROBE TIP FROM WALL-FT. | VELOCITY HEAD - IN. H2O TRAVERSE NUMBER 1 |
|---|---|---|
| 1 | 0.190 | 0.200 |
| 2 | 0.590 | 0.280 |
| 3 | 1.022 | 0.350 |
| 4 | 1.495 | 0.380 |
| 5 | 2.024 | 0.400 |
| 6 | 2.637 | 0.440 |
| 7 | 3.390 | 0.430 |
| 8 | 4.485 | 0.430 |
| 8 | 4.485 | 0.410 |
| 7 | 3.390 | 0.430 |
| 6 | 2.637 | 0.420 |
| 5 | 2.024 | 0.420 |
| 4 | 1.495 | 0.390 |
| 3 | 1.022 | 0.330 |
| 2 | 0.590 | 0.270 |
| 1 | 0.190 | 0.250 |
| AV. SQ. ROOT | | 0.600 |

| | |
|---|---|
| AVERAGE STATIC PRESSURE | -3.56 CM. H20 |
| AVERAGE FLUE GAS TEMPERATURE | 432. DEG.C |
| PITOT TUBE CALIBRATION FACTOR | 0.804 |
| OVERALL AVERAGE SQUARE ROOT | 0.600 |
| AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL | 16.730 M/SEC - MEAS. |
| STACK TOP | 16.730 M/SEC - CALC. |
| TOTAL FLUE GAS FLOW RATE | 64.103 M3/S* |
| | 9555.965 KMOLS/HR |
| SULPHUR DIOXIDE EMISSION RATE | 0.218 M3/S* |
| | 50.020 TONNE/D SO2 |
| | 25.010 TONNE/D SULPHUR |

* VOLUMES EXPRESSED AT 21.1 C AND 760 MM HG

ADRP


VELOCITY PROFILE 1 TEST 5
VELOCITY HEAD IN INCHES OF WATER
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.0
1.2
2.4
3.6
4.8
6.0
7.2
8.4
9.6
10.8
12.0
DISTANCE ACROSS STACK - FT.

ADRP CROSSFIELD INCINERATOR STACK

EMISSION CALCULATIONS

TEST NUMBER 6 PAGE 1 DATE AUGUST 22.1985

| | |
|---|---|
| LOCATION OF SAMPLING POINT | 147 FOOT LEVEL |
| INSIDE DIAMETER OF STACK AT SAMPLING POINT | 3.65 METERS |
| INSIDE DIAMETER OF STACK AT TOP | 3.65 METERS |
| BAROMETRIC PRESSURE | 671.32 MM. HG |
| AMBIENT TEMPERATURE | 24. DEG.C |

CARBON DIOXIDE ANALYSIS
GAS CHROMATOGRAPHY 7.64 PERCENT-DRY BASIS
OXYGEN ANALYSIS
GAS CHROMATOGRAPHY 6.70 PERCENT-DRY BASIS

AVERAGE COMPOSITION OF FLUE GAS

| | DRY BASIS PERCENT | WET BASIS PERCENT |
|---|---|---|
| O2 | 6.70 | 5.27 |
| CO2 | 7.64 | 6.01 |
| N2 * | 85.66 | 67.41 |
| H2O | | 20.97 |
| SO2 | | 0.34 |

* BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00) 0.939

SULPHUR DIOXIDE ANALYSIS

| | | |
|---|---|---|
| GAS SAMPLE METERED | 13.05 | CU.FT. |
| GAS SAMPLE TEMPERATURE | 52. | DEG.C |
| VACUUM AT METER | 0.0 | MM.HG. |
| VACUUM AT CONDENSER | 50.80 | MM.HG. |
| VOLUME OF WATER COLLECTED | 56.00 | CC. |
| VOLUME OF BA(CLO4)2 USED | 1065.00 | CC. |
| NORMALITY OF BA(CLO4)2 | 0.10 | N. |
| VAP.PRES.OF H2O-IMPINGER TEMP. | 0.30 | IN. OF HG. |
| AVERAGE SO2 CONCENTRATION | 0.3389 | PERCENT-WET BASIS |

TOTAL VOL OF GAS SAMPLED 16.58 CU.FT. (METER CONDITIONS)

ADRP CROSSFIELD INCINERATOR STACK

EMISSION CALCULATIONS

TEST NUMBER 6 PAGE 2 DATE AUGUST 22.1985

FLUE GAS FLOW RATE

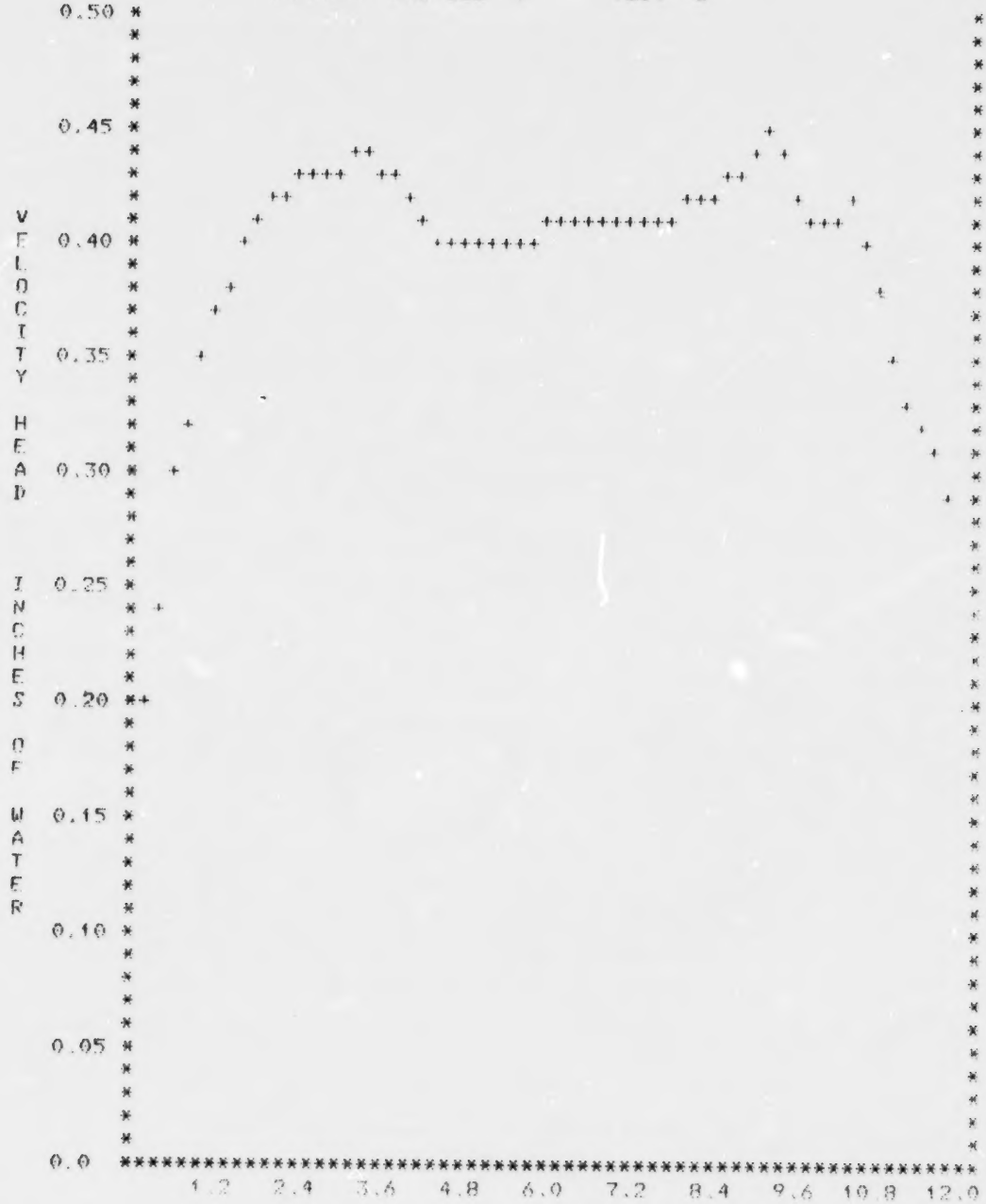
| SECTOR | PROBE TIP FROM WALL-FT. | VELOCITY HEAD - IN. H2O TRAVERSE NUMBER 1 |
|---|---|---|
| 1 | 0.190 | 0.200 |
| 2 | 0.590 | 0.270 |
| 3 | 1.022 | 0.350 |
| 4 | 1.495 | 0.390 |
| 5 | 2.024 | 0.420 |
| 6 | 2.637 | 0.430 |
| 7 | 3.390 | 0.440 |
| 8 | 4.485 | 0.400 |
| 8 | 4.485 | 0.410 |
| 7 | 3.390 | 0.420 |
| 6 | 2.637 | 0.450 |
| 5 | 2.024 | 0.400 |
| 4 | 1.495 | 0.420 |
| 3 | 1.022 | 0.360 |
| 2 | 0.590 | 0.320 |
| 1 | 0.190 | 0.290 |
| AV. SQ. ROOT | | 0.608 |

| | |
|---|---|
| AVERAGE STATIC PRESSURE | -3.56 CM. H20 |
| AVERAGE FLUE GAS TEMPERATURE | 430. DEG.C |
| PITOT TUBE CALIBRATION FACTOR | 0.804 |
| OVERALL AVERAGE SQUARE ROOT | 0.608 |
| AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL | 16.905 M/SEC - MEAS. |
| STACK TOP | 16.905 M/SEC - CALC. |
| TOTAL FLUE GAS FLOW RATE | 64.980 M3/S* |
| | 9686.703 KMOLS/HR |
| SULPHUR DIOXIDE EMISSION RATE | 0.220 M3/S* |
| | 50.534 TONNE/D SO2 |
| | 25.267 TONNE/D SULPHUR |

* VOLUMES EXPRESSED AT 21.1 C AND 760 MM HG

ADRP

VELOCITY PROFILE 1 TEST 6



GAS CHROMATOGRAPHIC ANALYSES

A.D.R.P.
CROSSFIELD

AUGUST 21/22.1985
FILE NUMBER 5390

| SITE | 08/21 | 08/21 | 08/21 | 08/22 | 08/22 | 08/22 |
|---|---|---|---|---|---|---|
| TIME | 12.22 | 14.09 | 15.16 | 16.46 | 17.19 | 18.40 |
| H2 | 0.7107 | 0.6783 | 0.6557 | 0.7307 | 0.7051 | 0.7008 |
| A | 0.9877 | 0.9902 | 0.9881 | 0.9882 | 0.9909 | 0.9897 |
| O2 | 7.1516 | 6.9385 | 7.4020 | 6.8709 | 6.6464 | 6.6972 |
| N2 | 82.5824 | 82.7902 | 82.6202 | 82.6268 | 82.8535 | 82.7542 |
| C1 | 0.2328 | 0.2197 | 0.2296 | 0.2231 | 0.2274 | 0.2190 |
| CO | 0.5842 | 0.5913 | 0.5500 | 0.6375 | 0.6210 | 0.6169 |
| CO2 | 7.3947 | 7.4162 | 7.2144 | 7.5453 | 7.6087 | 7.6381 |
| C2+ | 0.0089 | 0.0078 | 0.0080 | 0.0083 | 0.0071 | 0.0102 |
| H2S | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0166 | 0.0159 | 0.0163 | 0.0164 | 0.0153 | 0.0163 |
| SO2 | 0.3231 | 0.3441 | 0.3081 | 0.3456 | 0.3180 | 0.3505 |
| CS2 | 0.0073 | 0.0078 | 0.0076 | 0.0072 | 0.0066 | 0.0071 |
| TOTAL | 100.0000 | 100.0000 | 100.0000 | 100.0000 | 100.0000 | 100.0000 |

MOLE PERCENT ON DRY BASIS

WESTERN RESEARCH, CALGARY, ALBERTA

OXIDES OF NITROGEN DETERMINATION
FIELD DATA

FILE # 5390
A.D.R.P.
CROSSFIELD
INCINERATOR STACK

08/22/85
TEMP(C) 24
B.P. MM 671.3
BY R.T./M.T.

| FLASK | TIME | SOLN. | VOLUME FLASK | EVAC. PRES. | FILLED PRES. | FLASK TEMP. |
|---|---|---|---|---|---|---|
| 7 | 16.15 | 30 | 2073.50 | 627.4 | -2.5 | 24 |
| 17 | 16.18 | 30 | 2102.80 | 621 | 0 | 24 |
| 6 | 17.52 | 30 | 2033.40 | 624.8 | 0 | 24 |
| 11 | 17.54 | 30 | 2086.60 | 617.2 | -2.5 | 24 |
| 4 | 18.16 | 30 | 2105.20 | 622.3 | 0 | 24 |
| 10 | 18.21 | 30 | 2080.70 | 622.3 | 0 | 24 |

LAB DATA

08/26/85
TEMP (C) 20
B.P. MM 678.7

CALIBRATION DATA
SLOPE .8823
INTERCEPT .018

| FLASK | PRESSURE | TEMP. | ABS. | DILUTION PPM NO2 |
|---|---|---|---|---|
| 7 | -48.3 | 20 | .01 | 8.89 |
| 17 | -30.5 | 20 | .01 | 8.59 |
| 6 | -40.6 | 20 | .01 | 8.99 |
| 11 | -40.6 | 20 | 0 | 0.00 |
| 4 | -17.8 | 20 | 0 | 0.00 |
| 10 | -30.5 | 20 | 0 | 0.00 |

OXIDES OF NITROGEN DETERMINATION
FIELD DATA

FILE # 5390 08/21/85
A.D.R.P.
CROSSFIELD
INCINERATOR STACK
TEMP(C) 10
B.P. MM 670.6
BY R.T./M.T.

| FLASK | TIME | SOLN. | VOLUME FLASK | EVAC. PRES. | FILLED PRES. | FLASK TEMP. |
|---|---|---|---|---|---|---|
| 34 | 12.29 | 30 | 2001.00 | 614.7 | 0 | 11 |
| 30 | 12.31 | 30 | 2012.00 | 617.2 | 0 | 11 |
| 31 | 14.13 | 30 | 2007.00 | 619.8 | 0 | 11 |
| 32 | 14.16 | 30 | 2002.00 | 617.2 | 0 | 11 |
| 15 | 15.01 | 30 | 2027.30 | 619.8 | 0 | 11 |
| 3 | 15.03 | 30 | 2054.30 | 619.8 | 0 | 11 |

LAB DATA

08/26/85
TEMP (C) 20
B.P. MM 678.7

CALIBRATION DATA
SLOPE .8823
INTERCEPT .018

| FLASK | PRESSURE | TEMP. | ABS. | DILUTION PPM NO2 |
|---|---|---|---|---|
| 34 | -5.1 | 20 | 0 | 0.00 |
| 30 | 0 | 20 | .01 | 8.63 |
| 31 | 5.1 | 20 | .02 | 11.35 |
| 32 | -7.6 | 20 | 0 | 0.00 |
| 15 | -17.8 | 20 | 0 | 0.00 |
| 3 | 0 | 20 | 0 | 0.00 |

## 2. $NO_x$ SOURCE SAMPLING PROGRAM

In addition to the testing work conducted at one of the sour gas (extraction) plants located near Crossfield (see Section 1), a source sampling program was conducted in order to establish Alberta specific $NO_x$ emission factors for natural gas fueled reciprocating and turbine engines. These are the major industrial sources of $NO_x$ emissions in Alberta, accounting for approximately three quarters of the total $NO_x$ emissions by industrial sources. Waste gas incinerators were also included in the program as there was some question regarding the importance of these as $NO_x$ emission sources.

Initially eighteen sources were surveyed (i.e., six reciprocating engines, six turbine engines and three waste gas incinerator units), with intentions to conduct additional sampling following a preliminary review of the survey results. The preliminary results indicated that the waste gas incinerators used in Alberta are not significant sources of $NO_x$ emissions. The average $NO_x$ emission rate of 0.0337 t/d which was determined is roughly that which a 100 kW natural gas fueled reciprocating engine would be expected to produce. The preliminary results also indicated that the variability of $NO_x$ emission factor values for reciprocating engines is quite high, with the precision of these (i.e., the mean divided by the standard deviation), being in excess of a value of 1.0. The precision of $NO_x$ emission factor values determined for the turbine engines was less than half this value.

In view of the poor precision of the $NO_x$ emission factors determined for reciprocating engines it was decided to survey six more of these units. No additional waste gas incinerator units or turbine engines were surveyed.

For each of the twenty-one $NO_x$ emission sources surveyed (i.e., twelve reciprocating engines, six turbine engines and three waste gas incinerator units), a formal report was prepared which identifies the sampling and analysis methods used, delineates the analytic procedures employed, and tabulates the field and laboratory data. These are presented in the following subsections:

Section 2.1 - Individual Reports of the Reciprocating Engines

Section 2.2 - Individual Reports of the Turbine Engines

Section 2.3 - Individual Reports of the Waste Gas Incinerator Units

The publications which are referenced in these reports are listed in Section 2.4.

The overall results of the $NO_x$ source sampling program are summarized and discussed in Volume 2, Section 3.2.3.

## 2.1 INDIVIDUAL REPORTS OF THE SURVEYED RECIPROCATING ENGINES

The individual reports that were prepared for each the twenty-one reciprocating engines surveyed are presented in the following. Since the Introduction and Procedure sections of each report are basically the same, these have been omitted from all but the first report to avoid duplication.

## 2.1.1 Natural Gas Fueled Engines: $NO_x$ Test Report No. R-1

Test Date: October 7, 1985
Test Location: Sylvan Lake area
Tested By: M. Towill & B. Reshetylo

### 2.1.1.1 Summary

A 600 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 83.8 ng/J was obtained. This is approximately 94% lower than the value of 1481 ng/J (55 400 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency (1985) for typical industrial natural gas fueled reciprocating engines. The significantly lower emission factor obtained here is likely due to the rich fuel-air mixture (i.e., insufficient air for stoichiometric combustion) on which the engine operated. With such a fuel mixture, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of $NO_x$.

### 2.1.1.2 Introduction

In Alberta, the primary industrial source of NOx emissions is the internal combustion engine (i.e., large turbine and reciprocating engines). The amount of $NO_x$ emitted from these units is normally estimated by using emission factors. Emission factors express $NO_x$ emissions in terms of nanograms per joule of fuel consumed (ng/J).

Production of $NO_x$ is a complex process. Ambient temperature, pressure and humidity, and operating conditions are all known to have a significant effect. Subsequently, the use of emission

factors provides only a rough approximation of actual emissions. In order to obtain $NO_x$ emission factors that will best approximate $NO_x$ emissions in Alberta, a number of representative emission sources are being tested (Alberta-specific emission factors are not currently available).

In Alberta, the vast majority of industrial turbine and reciprocating engines are natural gas fueled. Therefore, only natural gas fueled engines are being considered.

A minimum of six turbine engines and six reciprocating engines of various power levels will be tested. In this report, $NO_x$ testing of a 600 kW reciprocating engine is discussed.

2.1.1.3 Procedure

(1) The following basic data were recorded:

- location,
- date,
- ambient temperature,
- relative humidity,
- barometric pressure,
- test crew, and
- test unit description.

(2) One duplicate flue gas sample and one fuel gas sample were collected and subsequently analyzed by a gas chromatograph. These analyses were used to obtain a single representative NOx and $H_2O$ free composition of both the fuel and flue gases.

(3) The moisture content of the flue gas was determined using a half hour condensation test as described under Method 3 in the Alberta Environment Stack Sampling Code (1976).

Any natural gas mixture supplied as fuel to an internal combustion engine will contain much less than 1% $H_2O$. Moisture levels of this magnitude are insignificant in terms of calculating $NO_x$ emission factors. Therefore, moisture content of the fuel gas was not determined.

(4) The $NO_x$ content of the flue gas was determined using the $NO_x$ testing procedure described under Method 6 in the Alberta Environment Stack Sampling Code (1976). Two triplicate tests were performed (i.e., 6 $NO_x$ samples were taken). Results of these tests were used to obtain a single representative NOx concentration for the flue gas.

(5) Using the results of (2), (3) and (4) an overall representative composition was determined for the flue gas. The overall reaction for the combustion process is expressed as:

$$\begin{bmatrix}\text{Overall}\\ \text{Fuel Gas}\\ \text{Composition}\end{bmatrix} + a \begin{bmatrix}\text{Overall}\\ \text{Composition}\\ \text{of the Air}\end{bmatrix} \rightarrow b \begin{bmatrix}\text{Overall}\\ \text{Flue Gas}\\ \text{Composition}\end{bmatrix} \qquad (1)$$

where "a" and "b" are stoichiometric coefficients. If it is assumed that the concentration of carbon compounds is negligible in the air then the coefficient "b" may be obtained by balancing the carbon atoms between the fuel gas and the flue gas compositions.

An analysis of the air was not conducted nor was "a" evaluated, as this information was not required.

The $NO_x$ emission factor was calculated using the following equation:

$$EF = \frac{y\,(NO_x) \cdot b \cdot M\,(NO_2) \cdot g_c}{\text{100 kmoles of fuel gas} \cdot \Delta H} \qquad (2)$$

where,

EF = $NO_x$ emission factor, ng of $NO_x$/J of fuel gas

y ($NO_x$) = mole percent of $NO_x$ expressed as an $NO_2$ equivalent

M ($NO_2$) = molecular weight of $NO_2$
= 46.0055 kg/kmole

$g_c$ = conversion factor
= $10^6$

$\Delta H$ = gross heat value of the fuel gas, MJ/kmole

2.1.1.4 Results

(1) Basic Data:

Field Work

Date: October 7, 1985
Location: Sylvan Lake area
Test Crew: M. Towill
B. Reshetylo

Test Unit: Make - Superior White
Model - 86-825
Rated Power Level - 600 kW at 900 RPM
Service - Driver for a natural gas compressor

Ambient Temperature: 18°C
Barometric Pressure: 676 mm Hg
Relative Humidity: 67%

Lab Work

Date: October 21, 1985
Location: Calgary
Ambient Temperature: 21°C
Barometric Pressure: 658.8 mm Hg

(2) Gas Analysis:

Table 3. Flue gas composition: $NO_x$ test report No. R-1.

| Component | Mole Percent Sample 1 | Sample 2 | Representative* Composition |
|---|---|---|---|
| $H_2$ | 4.2810 | 2.0008 | 4.2810 |
| Ar | 0.9584 | 0.9280 | 0.9584 |
| $O_2$ | 0.3595 | 7.7121 | 0.3595 |
| $N_2$ | 80.1357 | 77.5898 | 80.1357 |
| $C_1$ | 0.2070 | 0.1300 | 0.2070 |
| CO | 6.2204 | 2.9327 | 6.2204 |
| $CO_2$ | 7.8135 | 8.6955 | 7.8135 |
| $C_2$ | 0.0209 | 0.0097 | 0.0209 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0036 | 0.0014 | 0.0036 |
| | 100.0000 | 100.0000 | 100.0000 |

* The representative composition was taken to be that of sample 1. Sample 2 had an abnormally high $O_2$ concentration and therefore was suspect of air contamination.

Table 4. Fuel gas composition: $NO_x$ test report No. R-1.

| Component | Mole Percent |
|---|---|
| $H_2$ | 0.0000 |
| Ar | 0.0201 |
| $O_2$ | 0.0000 |
| $N_2$ | 1.6820 |
| $C_1$ | 79.7729 |
| CO | 0.0000 |
| $CO_2$ | 2.8188 |
| $C_2$ | 9.6043 |
| $H_2S$ | 0.0000 |
| COS | 0.0000 |
| $C_3$ | 4.0671 |
| $SO_2$ | 0.0000 |
| $CS_2$ | 0.0000 |
| i-$C_4$ | 0.5547 |
| n-$C_4$ | 1.1536 |
| i-$C_5$ | 0.1465 |
| n-$C_5$ | 0.0715 |
| $C_6$ | 0.0853 |
| $C_7$+ | 0.0230 |
| | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.1124 $m^3$ |
| Meter Pressure - | 675.9 mm Hg |
| Meter Temperature - | 15.3°C |
| Impinger Pressure - | 637.8 mm Hg |
| Moles of Dried Flue Gas Metered - | 4.22 g - moles |
| Volume of $H_2O$ Condensed - | 13 ml |
| Moles of $H_2O$ Condensed - | 0.72 g - moles |
| Vapour Pressure of Drier - | 6.774 mm Hg |
| Moles of $H_2O$ Vapour - | 0.05 g - moles |
| Total Moles of Wet Flue Gas - | 4.99 g - moles |
| $H_2O$ Concentration - | 15.34 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 5. $NO_x$ determination - field data: $NO_x$ test report No. R-1.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 10 | 14:24 | 30 | 2080.7 | 53.70 | 678.54 | 18 |
| 6 | 14:27 | 30 | 2033.4 | 47.35 | 701.40 | 18 |
| 7 | 14:37 | 30 | 2073.5 | 47.35 | 696.32 | 18 |
| 35 | 15:27 | 30 | 2002.0 | 66.40 | 645.52 | 18 |
| 34 | 15:31 | 30 | 2003.0 | 53.70 | 683.62 | 18 |
| 30 | 15:33 | 30 | 2010.0 | 60.05 | 681.08 | 18 |

(b) Lab Data:

Table 6. $NO_x$ determination - lab data: $NO_x$ test report No. R-1.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 10 | 658.80 | 21 | 184.38 |
| 6 | 658.80 | 21 | 166.98 |
| 7 | 663.88 | 21 | 182.46 |
| 35 | 661.34 | 21 | 204.55 |
| 34 | 663.88 | 21 | 185.88 |
| 30 | 668.96 | 21 | 175.01 |

Representative $NO_x$ Concentration**: 181.93 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 7. Overall gas compositions: $NO_x$ test report No. R-1.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 15.3400 |
| $NO_x$ | 0.0000 | 0.0000 | 0.0182 |
| $H_2$ | 0.0000 | 4.2810 | 3.6235 |
| Ar | 0.0201 | 0.9584 | 0.8112 |
| $O_2$ | 0.0000 | 0.3595 | 0.3043 |
| $N_2$ | 1.6820 | 80.1357 | 67.8283 |
| CO | 0.0000 | 6.2204 | 5.2651 |
| $CO_2$ | 2.8188 | 7.8135 | 6.6135 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 79.7729 | 0.2070 | 0.1752 |
| $C_2$ | 9.6043 | 0.0209 | 0.0177 |
| $C_3$ | 4.0671 | 0.0036 | 0.0030 |
| i-$C_4$ | 0.5547 | 0.0000 | 0.0000 |
| n-$C_4$ | 1.1538 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.1465 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0715 | 0.0000 | 0.0000 |
| $C_6$ | 0.0853 | 0.0000 | 0.0000 |
| $C_7$+ | 0.0230 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 10.1335

Gross heating value of fuel gas = 42.84 $MJ/m^3$

= 1012 MJ/kmole

(c) NOx Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.01819 \cdot 10.1335 \cdot 46.0055 \cdot 10^6}{100 \cdot 1012}$$

$$= 83.8 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 94% less than this EPA number. This large difference is likely due to the rich fuel-air mixture which was used (i.e., insufficient air for stoichiometric combustion). This is evident in Table 7 where it can be seen that the overall flue gas composition contains significant concentrations of combustibles (i.e., $H_2$, CO, $C_1$, $C_2$ and $C_3$).

With rich fuel-air mixtures, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of $NO_x$.

2.1.1.5 Conclusions

The tested engine was not, from a thermodynamic point of view, operating at optimal conditions. The engine used a rich fuel-air mixture which has resulted in the relatively low $NO_x$ emission factor of 83.8 ng/J.

## 2.1.2 Natural Gas Fueled Engines: $NO_x$ Test Report No. R-2

Test Date: January 14, 1986
Test Location: Gilby area
Tested By: T. Seedhouse & C. Scott

### 2.1.2.1 Summary

A 820 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 2797 ng/J was obtained. This is approximately 89% higher than the value of 1481 ng/J (55 400 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

### 2.1.2.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

### 2.1.2.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

### 2.1.2.4 Results

(1) Basic Data:

Field Work

Date: January 14, 1986
Location: Gilby area
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Superior White
Model - 8GT-825
Rated Power Level - 820 kW at 900 RPM
Service - Driver for a natural gas compressor

Ambient Temperature: 12.0°C
Barometric Pressure: 669.29 mm Hg
Relative Humidity: 26%

Lab Work

Date: January 15, 1986
Location: Calgary
Ambient Temperature: 21.2°C
Barometric Pressure: 659.44 mm Hg

(2) Gas Analysis:

Table 8. Flue gas composition: $NO_x$ test report No. R-2.

| Component | Mole Percent Sample 1 | Sample 2 | Average Composition |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.9942 | 0.9960 | 0.9951 |
| $O_2$ | 7.4590 | 7.1327 | 7.2958 |
| $N_2$ | 83.1257 | 83.2805 | 83.2030 |
| $C_1$ | 0.3293 | 0.3313 | 0.3303 |
| CO | 0.0643 | 0.0638 | 0.0640 |
| $CO_2$ | 7.9559 | 8.1473 | 8.0516 |
| $C_2$ | 0.0332 | 0.0284 | 0.0308 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0135 | 0.0084 | 0.0110 |
| $iC_4$ | 0.0107 | 0.0059 | 0.0083 |
| $nC_4$ | 0.0099 | 0.0058 | 0.0079 |
| $iC_5$ | 0.0012 | 0.0000 | 0.0006 |
| $nC_5$ | 0.0033 | 0.0000 | 0.0016 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 9: Fuel gas composition: $NO_x$ test report No. R-2.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.0000 | 0.0000 |
| $O_2$ | 0.0000 | 0.0000 | 0.0000 |
| $N_2$ | 0.5703 | 0.5783 | 0.5743 |
| $C_1$ | 82.3264 | 82.1873 | 82.2568 |
| CO | 0.0000 | 0.0000 | 0.0000 |
| $CO_2$ | 4.4282 | 4.4733 | 4.4508 |
| $C_2$ | 8.5449 | 8.5470 | 8.5459 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 2.8091 | 2.8832 | 2.8462 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.3702 | 0.3779 | 0.3741 |
| n-$C_4$ | 0.6736 | 0.6907 | 0.6821 |
| i-$C_5$ | 0.1235 | 0.1165 | 0.1200 |
| n-$C_5$ | 0.1296 | 0.1181 | 0.1238 |
| $C_6$+ | 0.0242 | 0.0278 | 0.0260 |
| | 100.0000 | 100.0000 | 100.0000 |

(3) Flué Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.1873 $m^3$ |
| Meter Pressure - | 669.29 mm Hg |
| Meter Temperature - | 16.2°C |
| Impinger Pressure - | 605.79 mm Hg |
| Moles of Dried Flue Gas Metered - | 6.95 g - moles |
| Volume of $H_2O$ Condensed - | 10 ml |
| Moles of $H_2O$ Condensed - | 0.55 g - moles |
| Vapour Pressure of Drier - | 8.905 mm Hg |
| Moles of $H_2O$ Vapour - | 0.10 g - moles |
| Total Moles of Wet Flue Gas - | 7.61 g - moles |
| $H_2O$ Concentration - | 8.65 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 10. $NO_x$ determination - field data: $NO_x$ test report No. R-2.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 31 | 12:55 | 30 | 2011.0 | 48.26 | 669.29 | 10 |
| 8 | 12:58 | 30 | 2067.5 | 39.37 | 669.29 | 10 |
| 3 | 13:01 | 30 | 2054.3 | 39.37 | 669.29 | 10 |
| 33 | 13:41 | 30 | 2008.0 | 38.10 | 669.29 | 10 |
| 34 | 13:44 | 30 | 2003.0 | 36.83 | 666.75 | 10 |
| 6 | 13:46 | 30 | 2033.4 | 44.45 | 669.29 | 10 |

(b) Lab Data:

Table 11. $NO_x$ determination - lab data: $NO_x$ test report No. R-2.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 31 | 674.68 | 21 | 4342.65 |
| 8 | 674.68 | 21 | 3878.82 |
| 3 | 672.14 | 21 | 3835.73 |
| 33 | 674.68 | 21 | 3953.07 |
| 34 | 677.22 | 21 | 3841.17 |
| 6 | 674.68 | 21 | 3995.01 |

Representative $NO_x$ Concentration**: 3917.02 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 12. Overall gas compositions: $NO_x$ test report No. R-2.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 8.6500 |
| $NO_x$ | 0.0000 | 0.0000 | 0.3917 |
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.9951 | 0.9051 |
| $O_2$ | 0.0000 | 7.2958 | 6.6361 |
| $N_2$ | 0.5743 | 83.2030 | 75.6800 |
| CO | 0.0000 | 0.0640 | 0.0582 |
| $CO_2$ | 4.4508 | 8.0516 | 7.3236 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 82.2568 | 0.3303 | 0.3005 |
| $C_2$ | 8.5459 | 0.0308 | 0.0280 |
| $C_3$ | 2.8462 | 0.0110 | 0.0100 |
| i-$C_4$ | 0.3741 | 0.0083 | 0.0076 |
| n-$C_4$ | 0.6821 | 0.0079 | 0.0072 |
| i-$C_5$ | 0.1200 | 0.0006 | 0.0005 |
| n-$C_5$ | 0.1238 | 0.0016 | 0.0015 |
| $C_6$ | 0.0260 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 15.0484

Gross heating value of fuel gas = 41.02 $MJ/m^3$

= 969 MJ/kmole

(c) $NO_x$ Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.3917 \cdot 15.0484 \cdot 46.0055 \cdot 10^6}{100 \cdot 969}$$

$$= 2797 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 89% higher than this EPA number.

2.1.2.5 Conclusions

The $NO_x$ emission factor for the tested reciprocating engine is 2797 ng/J.

## 2.1.3 Natural Gas Fueled Engines: $NO_x$ Test Report No. R-3

Test Date: January 16, 1986
Test Location: Sylvan Lake Area
Tested By: C. Scott & B. Reshetylo

### 2.1.3.1 Summary

A 600 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 147.6 ng/J was obtained. This is approximately 90% lower than the value of 1481 ng/J (55 400 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines. The significantly lower emission factor which has been obtained here is likely due to the rich fuel-air mixture (i.e., insufficient air for stoichiometric combustion) on which the engine operated. With such a fuel mixture, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of $NO_x$.

### 2.1.3.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

### 2.1.3.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.3.4 Results

(1) Basic Data:

Field Work

Date: January 16, 1986
Location: Sylvan Lake Area
Test Crew: C. Scott & B. Reshetylo

Test Unit: Make - Superior White
Model - 86-825
Rated Power Level - 600 kW at 900 RPM
Service - Driver for a natural gas compressor

Ambient Temperature: 3°C
Barometric Pressure: 644.2 mm Hg
Relative Humidity: 39%

Lab Work

Date: January 22, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 660.54 mm Hg

(2) Gas Analysis:

Table 13. Flue gas composition: $NO_x$ test report No. R-3.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 2.5192 | 2.5294 | 2.5243 |
| Ar | 0.9729 | 0.9717 | 0.9723 |
| $O_2$ | 0.2256 | 0.2159 | 0.2208 |
| $N_2$ | 81.3501 | 81.2445 | 81.2973 |
| $C_1$ | 0.1130 | 0.1116 | 0.1123 |
| CO | 4.9057 | 4.9044 | 4.9050 |
| $CO_2$ | 9.8754 | 9.9978 | 9.9366 |
| $C_2$ | 0.0191 | 0.0194 | 0.0192 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0041 | 0.0040 | 0.0041 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_4$ | 0.0127 | 0.0003 | 0.0065 |
| $nC_4$ | 0.0022 | 0.0010 | 0.0016 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 14. Fuel gas composition: $NO_x$ test report No. R-3.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.0000 | 0.0000 |
| $O_2$ | 0.0000 | 0.0000 | 0.0000 |
| $N_2$ | 0.7091 | 0.6365 | 0.6728 |
| $C_1$ | 77.9237 | 78.3689 | 78.1463 |
| CO | 0.0000 | 0.0000 | 0.0000 |
| $CO_2$ | 3.0773 | 3.0365 | 3.0569 |
| $C_2$ | 10.8775 | 10.8163 | 10.8469 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 4.5590 | 4.4743 | 4.5166 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.7130 | 0.6897 | 0.7014 |
| n-$C_4$ | 1.3239 | 1.2606 | 1.2923 |
| i-$C_5$ | 0.3075 | 0.2658 | 0.2866 |
| n-$C_5$ | 0.3155 | 0.2689 | 0.2922 |
| $C_6$ | 0.1529 | 0.1447 | 0.1488 |
| $C_7$+ | 0.0406 | 0.0378 | 0.0392 |
| | 100.0000 | 100.0000 | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.2306 $m^3$ |
| Meter Pressure - | 664.21 mm Hg |
| Meter Temperature - | 18.3°C |
| Impinger Pressure - | 600.71 mm Hg |
| Moles of Dried Flue Gas Metered - | 8.43 g - moles |
| Volume of $H_2O$ Condensed - | 27 ml |
| Moles of $H_2O$ Condensed - | 1.50 g - moles |
| Vapour Pressure of Drier - | 6.916 mm Hg |
| Moles of $H_2O$ Vapour - | 0.10 g - moles |
| Total Moles of Wet Flue Gas - | 10.02 g - moles |
| $H_2O$ Concentration - | 15.91 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 15. $NO_x$ determination - field data: $NO_x$ test report No. R-3.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 9 | 13:10 | 30 | 2038.4 | 36.83 | 664.21 | 3 |
| 6 | 13:12 | 30 | 2033.4 | 40.64 | 664.21 | 3 |
| 34 | 13:16 | 30 | 2003.0 | 41.91 | 664.21 | 3 |
| 23 | 13:48 | 30 | 1992.7 | 41.91 | 664.21 | 3 |
| 27 | 13:50 | 30 | 2020.0 | 43.18 | 664.21 | 3 |
| 22 | 13:53 | 30 | 2024.7 | 44.45 | 664.21 | 3 |

(b) Lab Data:

Table 16. $NO_x$ determination - lab data: $NO_x$ test report No. R-3.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 9 | 680.86 | 21.5 | 357.66 |
| 6 | 660.54 | 21.5 | 395.90 |
| 34 | 660.54 | 21.5 | 432.60 |
| 23 | 693.56 | 21.5 | 261.82 |
| 27 | 693.56 | 21.5 | 253.00 |
| 22 | 660.54 | 21.5 | 312.57 |

Representative $NO_x$ Concentration**: 331.99 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 17. Overall gas compositions: $NO_x$ test report No. R-3.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 15.9100 |
| $NO_x$ | 0.0000 | 0.0000 | 0.0332 |
| $H_2$ | 0.0000 | 2.5243 | 2.1218 |
| Ar | 0.0000 | 0.9723 | 0.8173 |
| $O_2$ | 0.0000 | 0.2208 | 0.1856 |
| $N_2$ | 0.6728 | 81.2973 | 68.3360 |
| CO | 0.0000 | 4.9050 | 4.1230 |
| $CO_2$ | 3.0569 | 9.9366 | 8.3524 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 78.1463 | 0.1123 | 0.0944 |
| $C_2$ | 10.8469 | 0.0192 | 0.0161 |
| $C_3$ | 4.5166 | 0.0041 | 0.0034 |
| i-$C_4$ | 0.7014 | 0.0065 | 0.0055 |
| n-$C_4$ | 1.2923 | 0.0016 | 0.0013 |
| i-$C_5$ | 0.2866 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.2922 | 0.0000 | 0.0000 |
| $C_6$ | 0.1488 | 0.0000 | 0.0000 |
| $C_7$+ | 0.0392 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 10.1651

Gross heating value of fuel gas = 44.50 $MJ/m^3$

= 1052 MJ/kmole

(c) NOx Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.033199 \cdot 10.1651 \cdot 46.0055 \cdot 10^6}{100 \cdot 1052}$$

= 147.6 ng/J

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 90% less than this EPA number. This large difference is likely due to the rich fuel-air mixture which was used (i.e., insufficient air for stoichiometric combustion). This is evident in Table 17 where it can be seen that the overall flue gas composition contains significant concentrations of combustibles (i.e., $H_2$, CO, $C_1$, $C_2$, $C_3$, i-$C_4$ and n-$C_4$).

With rich fuel-air mixtures, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of $NO_x$.

2.1.3.5 Conclusion

The tested engine was not, from a thermodynamic point of view, operating at optimal conditions. The engine used a rich fuel-air mixture which has resulted in the relatively low $NO_x$ emission factor of 147.6 ng/J.

## 2.1.4 Natural Gas Fueled Engines: $NO_x$- Test Report No. R-4

Test Date: January 16, 1986
Test Location: Sylvan Lake Area
Tested By: C. Scott & B. Reshetylo

### 2.1.4.1 Summary

A 895 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 83.3 ng/J was obtained. This is approximately 94% lower than the value of 1481 ng/J (55 400 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines. The significantly lower emission factor which has been obtained here is likely due to the rich fuel-air mixture (i.e., insufficient air for stoichiometric combustion) on which the engine operated. With such a fuel mixture, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of $NO_x$.

### 2.1.4.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

### 2.1.4.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.4.4 Results

(1) Basic Data:

Field Work

Date: January 16, 1986
Location: Sylvan Lake Area
Test Crew: C. Scott
B. Reshetylo

Test Unit: Make - Superior White
Model - 12G-825
Rated Power Level - 895 kW at 900 RPM
Service - Driver for a natural gas compressor

Ambient Temperature: 13°C
Barometric Pressure: 664.2 mm Hg
Relative Humidity: 39%

Lab Work

Date: January 22, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 660.54 mm Hg

(2) Gas Analysis:

Table 18. Flue gas composition: $NO_x$ test report No. R-4.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 3.0695 | 3.0713 | 3.0704 |
| Ar | 0.9667 | 0.9670 | 0.9668 |
| $O_2$ | 0.1644 | 0.1697 | 0.1671 |
| $N_2$ | 80.8285 | 80.8565 | 80.8425 |
| $C_1$ | 0.0409 | 0.0474 | 0.0442 |
| CO | 5.4586 | 5.4231 | 5.4408 |
| $CO_2$ | 9.4477 | 9.4404 | 9.4441 |
| $C_2$ | 0.0162 | 0.0167 | 0.0164 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0038 | 0.0054 | 0.0046 |
| $SO_2$ | 0.0020 | 0.0019 | 0.0020 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.0006 | 0.0002 | 0.0004 |
| n-$C_4$ | 0.0011 | 0.0004 | 0.0007 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 19. Fuel gas composition: $NO_x$ test report No. R-4.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.0000 | 0.0000 |
| $O_2$ | 0.0000 | 0.0000 | 0.0000 |
| $N_2$ | 0.6354 | 0.7454 | 0.6904 |
| $C_1$ | 78.7357 | 78.1897 | 78.4627 |
| CO | 0.0000 | 0.0000 | 0.0000 |
| $CO_2$ | 3.1345 | 3.1950 | 3.1647 |
| $C_2$ | 10.6944 | 10.7851 | 10.7398 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 4.3583 | 4.4502 | 4.4042 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.6595 | 0.6776 | 0.6686 |
| n-$C_4$ | 1.1849 | 1.2597 | 1.2223 |
| i-$C_5$ | 0.2408 | 0.2745 | 0.2577 |
| n-$C_5$ | 0.2348 | 0.2696 | 0.2522 |
| $C_6$ | 0.1079 | 0.1322 | 0.1200 |
| $C_7$+ | 0.0138 | 0.0210 | 0.0174 |
| | 100.0000 | 100.0000 | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.2304 $m^3$ |
| Meter Pressure - | 664.21 mm Hg |
| Meter Temperature - | 14.4°C |
| Impinger Pressure - | 600.71 mm Hg |
| Moles of Dried Flue Gas Metered - | 8.53 g - moles |
| Volume of $H_2O$ Condensed - | 30 ml |
| Moles of $H_2O$ Condensed - | 1.66 g - moles |
| Vapour Pressure of Drier - | 6.774 mm Hg |
| Moles of $H_2O$ Vapour - | 0.10 g - moles |
| Total Moles of Wet Flue Gas - | 10.29 g - moles |
| $H_2O$ Concentration - | 17.09 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 20. $NO_x$ determination - field data: $NO_x$ test report No. R-4.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 35 | 12:02 | 30 | 2002.0 | 33.01 | 664.21 | 3 |
| 3 | 12:05 | 30 | 2054.3 | 30.47 | 664.21 | 3 |
| 8 | 12:07 | 30 | 2067.5 | 31.74 | 664.21 | 3 |
| 17 | 12:42 | 30 | 2102.8 | 31.74 | 664.21 | 3 |
| 18 | 12:44 | 30 | 2041.2 | 34.28 | 664.21 | 3 |
| 33 | 12:47 | 30 | 2008.0 | 36.82 | 664.21 | 3 |

(b) Lab Data:

Table 21. $NO_x$ determination - lab data: $NO_x$ test report No. R-4.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 35 | 673.24 | 21.5 | 183.07 |
| 3 | 660.54 | 21.5 | 195.80 |
| 8 | 683.40 | 21.5 | 179.18 |
| 17 | 660.54 | 21.5 | 180.74 |
| 18 | 660.54 | 21.5 | 163.94 |
| 33 | 685.94 | 21.5 | 193.99 |

Representative $NO_x$ Concentration**: 184.25 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 22. Overall gas compositions: $NO_x$ test report No. R-4.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 17.0900 |
| $NO_x$ | 0.0000 | 0.0000 | 0.0184 |
| $H_2$ | 0.0000 | 3.0704 | 2.5451 |
| Ar | 0.0000 | 0.9668 | 0.8014 |
| $O_2$ | 0.0000 | 0.1671 | 0.1385 |
| $N_2$ | 0.6904 | 80.8425 | 67.0116 |
| CO | 0.0000 | 5.4408 | 4.5100 |
| $CO_2$ | 3.1647 | 9.4441 | 7.8284 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0020 | 0.0017 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 78.4627 | 0.0442 | 0.0366 |
| $C_2$ | 10.7398 | 0.0164 | 0.0136 |
| $C_3$ | 4.4042 | 0.0046 | 0.0038 |
| i-$C_4$ | 0.6686 | 0.0004 | 0.0003 |
| n-$C_4$ | 1.2223 | 0.0007 | 0.0006 |
| i-$C_5$ | 0.2577 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.2522 | 0.0000 | 0.0000 |
| $C_6$ | 0.1200 | 0.0000 | 0.0000 |
| $C_7$+ | 0.0174 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 10.2498

Gross heating value of fuel gas = 44.12 $MJ/m^3$
= 1043 MJ/kmole

(c) NOx Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.018425 \cdot 10.2498 \cdot 46.0055 \cdot 10^6}{100 \cdot 1043}$$

$$= 83.3 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 94% less than this EPA number. This large difference is likely due to the rich fuel-air mixture which was used (i.e., insufficient air for stoichiometric combustion). This is evident in Table 22 where it can be seen that the overall flue gas composition contains significant concentrations of combustibles (i.e., $H_2$, CO, $C_1$, $C_2$, $C_3$, i-$C_4$ and n-$C_4$).

With rich fuel-air mixtures, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of $NO_x$.

2.1.4.5 Conclusions

The tested engine was not, from a thermodynamic point of view, operating at optimal conditions. The engine used a rich fuel-air mixture which has resulted in the relatively low $NO_x$ emission factor of 83.3 ng/J.

## 2.1.5 Natural Gas Fueled Engines: $NO_x$ Test Report No. R-5

Test Date: January 16, 1986
Test Location: Sylvan Lake Area
Tested By: C. Scott & B. Reshetylo

### 2.1.5.1 Summary

A 480 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 323.1 ng/J was obtained. This is approximately 78% lower than the value of 1481 ng/J (55 400 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines. The significantly lower emission factor which has been obtained here is likely due to the rich fuel-air mixture (i.e., insufficient air for stoichiometric combustion) on which the engine operated. With such a fuel mixture, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of $NO_x$.

### 2.1.5.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

### 2.1.5.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

2.1.5.4 Results

(1) Basic Data:

Field Work

Date: January 16, 1986
Location: Sylvan Lake Area
Test Crew: C. Scott
B. Reshetylo

Test Unit: Make - Waukesha
Model - L-3711
Rated Power Level - 480 kW @ 1200 RPM
Service - Driver for a natural gas compressor

Ambient Temperature: 20°C
Barometric Pressure: 664.2 mm Hg
Relative Humidity: 39%

Lab Work

Date: January 22, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 660.54 mm Hg

(2) Gas Analysis:

Table 23. Flue gas composition: $NO_x$ test report No. R-5.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 1.8130 | 1.6634 | 1.7382 |
| Ar | 0.9906 | 0.9897 | 0.9901 |
| $O_2$ | 0.2001 | 0.2126 | 0.2063 |
| $N_2$ | 82.8240 | 82.7484 | 82.7862 |
| $C_1$ | 0.0717 | 0.1051 | 0.0884 |
| CO | 3.3337 | 3.3087 | 3.3212 |
| $CO_2$ | 10.7482 | 10.9469 | 10.8476 |
| $C_2$ | 0.0144 | 0.0150 | 0.0147 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0016 | 0.0016 | 0.0016 |
| $SO_2$ | 0.0027 | 0.0086 | 0.0057 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 24. Fuel gas composition: $NO_x$ test report No. R-5.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.0000 | 0.0000 |
| $O_2$ | 0.0000 | 0.0000 | 0.0000 |
| $N_2$ | 0.6389 | 0.6057 | 0.6223 |
| $C_1$ | 83.1210 | 83.2397 | 83.1804 |
| CO | 0.0000 | 0.0000 | 0.0000 |
| $CO_2$ | 3.4805 | 3.4403 | 3.4604 |
| $C_2$ | 10.9433 | 10.8837 | 10.9135 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 1.7866 | 1.8047 | 1.7956 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.0119 | 0.0119 | 0.0119 |
| n-$C_4$ | 0.0178 | 0.0140 | 0.0159 |
| i-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| $C_6$ | 0.0000 | 0.0000 | 0.0000 |
| $C_7$+ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.2063 $m^3$ |
| Meter Pressure - | 664.20 mm Hg |
| Meter Temperature - | 8.3°C |
| Impinger Pressure - | 600.70 mm Hg |
| Moles of Dried Flue Gas Metered - | 7.81 g - moles |
| Volume of $H_2O$ Condensed - | 26 ml |
| Moles of $H_2O$ Condensed - | 1.44 g - moles |
| Vapour Pressure of Drier - | 7.160 mm Hg |
| Moles of $H_2O$ Vapour - | 0.09 g - moles |
| Total Moles of Wet Flue Gas - | 9.34 g - moles |
| $H_2O$ Concentration - | 16.43 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 25. $NO_x$ determination - field data: $NO_x$ test report No. R-5.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 5 | 10:44 | 30 | 2041.5 | 34.28 | 664.20 | 5 |
| 2 | 10:47 | 30 | 2105.2 | 43.17 | 664.20 | 5 |
| 15 | 10:49 | 30 | 2027.3 | 41.90 | 661.66 | 5 |
| 20 | 11:31 | 30 | 2079.9 | 43.17 | 664.20 | 5 |
| 12 | 11:33 | 30 | 2032.0 | 36.82 | 661.66 | 5 |
| 10 | 11:35 | 30 | 2080.7 | 39.36 | 664.20 | 5 |

(b) Lab Data:

Table 26. $NO_x$ determination - lab data: $NO_x$ test report No. R-5.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 5 | 683.40 | 21.5 | 732.13 |
| 2 | 663.08 | 21.5 | 599.68 |
| 15 | 579.26 | 21.5 | 262.77 |
| 20 | 660.54 | 21.5 | 760.32 |
| 12 | 660.54 | 21.5 | 708.17 |
| 10 | 660.54 | 21.5 | 789.99 |

Representative $NO_x$ Concentration**: 700.08 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 27. Overall gas compositions: $NO_x$ test report No. R-5.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 16.4300 |
| $NO_x$ | 0.0000 | 0.0000 | 0.0700 |
| $H_2$ | 0.0000 | 1.7382 | 1.4514 |
| Ar | 0.0000 | 0.9901 | 0.8267 |
| $O_2$ | 0.0000 | 0.2063 | 0.1723 |
| $N_2$ | 0.6223 | 82.7862 | 69.1265 |
| CO | 0.0000 | 3.3212 | 2.7732 |
| $CO_2$ | 3.4604 | 10.8476 | 9.0577 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0057 | 0.0048 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 83.1804 | 0.0884 | 0.0738 |
| $C_2$ | 10.9135 | 0.0147 | 0.0123 |
| $C_3$ | 1.7956 | 0.0016 | 0.0013 |
| i-$C_4$ | 0.0119 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.0159 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| $C_6$ | 0.0000 | 0.0000 | 0.0000 |
| $C_7$+ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 9.5502

Gross heating value of fuel gas = 40.28 $MJ/m^3$
= 952 MJ/kmole

(c) $NO_x$ Emission Factor

Using equation (2), the NOx emission factor is given by:

$$EF = \frac{0.070008 \cdot 9.5502 \cdot 46.0055 \cdot 10^6}{100 \cdot 952}$$

$$= 323.1 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 78% less than this EPA number. This large difference is likely due to the rich fuel-air mixture which was used (i.e., insufficient air for stoichiometric combustion). This is evident in Table 27 where it can be seen that the overall flue gas composition contains significant concentrations of combustibles (i.e., $H_2$, CO, $C_1$, $C_2$ and $C_3$).

With rich fuel-air mixtures, available oxygen and overall combustion temperatures are lower than for more ideal combustion in which a slight excess of air is used. Both high temperature and available oxygen promote the formation of $NO_x$.

2.1.5.5 Conclusions

The tested engine was not, from a thermodynamic point of view, operating at optimal conditions. The engine used a rich fuel-air mixture which has resulted in the relatively low $NO_x$ emission factor of 323.1 ng/J.

## 2.1.6 Natural Gas Fueled Engines: $NO_x$ Test Report No. R-6

Test Date: February 24, 1986
Test Location: Moose Mountain
Tested By: T. Seedhouse & C. Scott

### 2.1.6.1 Summary

A 1200 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 715 ng/J was obtained. This is approximately 52% lower than the value of 1481 ng/J (55 400 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

### 2.1.6.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

### 2.1.6.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

### 2.1.6.4 Results

(1) Basic Data:

Field Work

Date: February 24, 1986
Location: Moose Mountain
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Superior White
Model - 16-C825
Rated Power Level - 1200 kW at 900 RPM
Service - Driver for a natural gas compressor

Ambient Temperature: 8.0°C
Barometric Pressure: 670.56 mm Hg
Relative Humidity: 53%

Lab Work

Date: February 26, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 674.40 mm Hg

(2) Gas Analysis:

Table 28. Flue gas composition: $NO_x$ test report No. R-6.

| Component | Mole Percent Sample 1 | Sample 2 | Average Composition |
|---|---|---|---|
| $H_2$ | 0.4664 | 0.4468 | 0.4566 |
| Ar | 1.0234 | 1.0236 | 1.0235 |
| $O_2$ | 0.1037 | 0.0567 | 0.0802 |
| $N_2$ | 85.5715 | 85.5821 | 85.5768 |
| $C_1$ | 0.0700 | 0.0709 | 0.0704 |
| CO | 0.6862 | 0.6912 | 0.6887 |
| $CO_2$ | 12.0712 | 12.1162 | 12.0937 |
| $C_2$ | 0.0057 | 0.0049 | 0.0053 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0019 | 0.0076 | 0.0048 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_5$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_5$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 29. Fuel gas composition: $NO_x$ test report No. R-6.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.0000 | 0.0000 |
| $O_2$ | 0.0000 | 0.0000 | 0.0000 |
| $N_2$ | 0.6380 | 0.6157 | 0.6269 |
| $C_1$ | 91.0040 | 90.9166 | 90.9603 |
| CO | 0.0000 | 0.0000 | 0.0000 |
| $CO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_2$ | 7.5861 | 7.6733 | 7.6297 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.7559 | 0.7780 | 0.7669 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.0049 | 0.0044 | 0.0046 |
| n-$C_4$ | 0.0055 | 0.0060 | 0.0058 |
| i-$C_5$ | 0.0023 | 0.0026 | 0.0024 |
| n-$C_5$ | 0.0033 | 0.0034 | 0.0034 |
| $C_6$+ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.2065 $m^3$ |
| Meter Pressure - | 670.56 mm Hg |
| Meter Temperature - | 15.8°C |
| Impinger Pressure - | 613.41 mm Hg |
| Moles of Dried Flue Gas Metered - | 7.68 g - moles |
| Volume of $H_2O$ Condensed - | 29 ml |
| Moles of $H_2O$ Condensed - | 1.61 g - moles |
| Vapour Pressure of Drier - | 6.015 mm Hg |
| Moles of $H_2O$ Vapour - | 0.08 g - moles |
| Total Moles of Wet Flue Gas - | 9.37 g - moles |
| $H_2O$ Concentration - | 17.96 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 30. $NO_x$ determination - field data: $NO_x$ test report No. R-6.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 6 | 11:46 | 30 | 2033.4 | 58.42 | 670.56 | 8 |
| 7 | 11:49 | 30 | 2073.5 | 62.23 | 670.56 | 8 |
| 9 | 12:23 | 30 | 2038.4 | 63.50 | 670.56 | 8 |
| 34 | 12:27 | 30 | 2003.0 | 68.58 | 670.56 | 8 |

(b) Lab Data:

Table 31. $NO_x$ determination - lab data: $NO_x$ test report No. R-6.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 6 | 641.38 | 21.5 | 1559.33 |
| 7 | 628.68 | 21.5 | 1285.28 |
| 9 | 643.92 | 21.5 | 1428.48 |
| 34 | 633.76 | 21.5 | 1441.10 |

Average $NO_x$ Concentration: 1428.55 ppm

* On a wet basis.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 32. Overall gas compositions: $NO_x$ test report No. R-6.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 17.9600 |
| $NO_x$ | 0.0000 | 0.0000 | 0.1429 |
| $H_2$ | 0.0000 | 0.4566 | 0.3739 |
| Ar | 0.0000 | 1.0235 | 0.8382 |
| $O_2$ | 0.0000 | 0.0802 | 0.0657 |
| $N_2$ | 0.6269 | 85.5768 | 70.0850 |
| CO | 0.0000 | 0.6867 | 0.5640 |
| $CO_2$ | 0.0000 | 12.0937 | 9.9044 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0048 | 0.0039 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 90.9603 | 0.0704 | 0.0577 |
| $C_2$ | 7.6297 | 0.0053 | 0.0043 |
| $C_3$ | 0.7669 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.0046 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.0058 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0024 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0034 | 0.0000 | 0.0000 |
| $C_6$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 10.3079

Gross heating value of fuel gas = 40.07 $MJ/m^3$
= 947 MJ/kmole

(c) NOx Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.1429 \cdot 10.3079 \cdot 46.0055 \cdot 10^6}{100 \cdot 947}$$

$$= 715 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 52% lower than this EPA number.

2.1.6.5 Conclusions

The $NO_x$ emission factor for the tested reciprocating engine is 715 ng/J.

## 2.1.7 Natural Gas Fueled Engines: $NO_x$ Test Report No. R-7

Test Date: February 25, 1986
Test Location: Crossfield - North
Tested By: T. Seedhouse & C. Scott

### 2.1.7.1 Summary

A 1500 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 719 ng/J was obtained. This is approximately 51% lower than the value of 1481 ng/J (55 400 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

### 2.1.7.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

### 2.1.7.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

### 2.1.7.4 Results

(1) Basic Data:

Field Work

Date: February 25, 1986
Location: Crossfield - North
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Deleval
Model - HT 80-2
Rated Power Level - 1500 kW at 600 RPM
Service - Driver for a natural gas compressor

Ambient Temperature: 6.0°C
Barometric Pressure: 671.58 mm Hg
Relative Humidity: 44%

Lab Work

Date: February 26, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 674.40 mm Hg

(2) Gas Analysis:

Table 33. Flue gas composition: $NO_x$ test report No. R-7.

| Component | Mole Percent Sample 1 | Sample 2 | Average Composition |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.9764 | 0.9799 | 0.9781 |
| $O_2$ | 11.6067 | 11.0016 | 11.3042 |
| $N_2$ | 81.6418 | 81.9291 | 81.7855 |
| $C_1$ | 0.2233 | 0.2567 | 0.2400 |
| CO | 0.0289 | 0.0319 | 0.0304 |
| $CO_2$ | 5.4942 | 5.7798 | 5.6370 |
| $C_2$ | 0.0213 | 0.0182 | 0.0197 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0074 | 0.0028 | 0.0051 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_5$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_5$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 34. Fuel gas composition: $NO_x$ test report No. R-7.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.0000 | 0.0000 |
| $O_2$ | 0.0000 | 0.0000 | 0.0000 |
| $N_2$ | 0.7675 | 0.5120 | 0.6398 |
| $C_1$ | 89.4824 | 90.1686 | 89.8255 |
| CO | 0.0000 | 0.0000 | 0.0000 |
| $CO_2$ | 0.1085 | 0.0793 | 0.0939 |
| $C_2$ | 9.2578 | 8.9558 | 9.1068 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.3838 | 0.2843 | 0.3340 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.0000 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| $C_6$+ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.2616 $m^3$ |
| Meter Pressure - | 671.58 mm Hg |
| Meter Temperature - | 19.7°C |
| Impinger Pressure - | 608.08 mm Hg |
| Moles of Dried Flue Gas Metered - | 9.62 g - moles |
| Volume of $H_2O$ Condensed - | 14 ml |
| Moles of $H_2O$ Condensed - | 0.78 g - moles |
| Vapour Pressure of Drier - | 5.685 mm Hg |
| Moles of $H_2O$ Vapour - | 0.09 g - moles |
| Total Moles of Wet Flue Gas - | 10.49 g - moles |
| $H_2O$ Concentration - | 8.26 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 35. $NO_x$ determination - field data: $NO_x$ test report No. R-7.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 15 | 10:17 | 30 | 2027.3 | 69.60 | 671.58 | 6 |
| 8 | 10:24 | 30 | 2067.5 | 75.95 | 671.58 | 6 |
| 18 | 10:27 | 30 | 2041.2 | 64.52 | 671.58 | 6 |
| 2 | 11:15 | 30 | 2105.2 | 69.60 | 671.58 | 6 |
| 5 | 11:18 | 30 | 2041.5 | 61.98 | 671.58 | 6 |
| 20 | 11:22 | 30 | 2079.9 | 64.52 | 671.58 | 6 |

(b) Lab Data:

Table 36. $NO_x$ determination - lab data: $NO_x$ test report No. R-7.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 15 | 738.15 | 21.5 | 688.02 |
| 8 | 775.24 | 21.5 | 1102.35 |
| 18 | 743.74 | 21.5 | 736.58 |
| 2 | 754.41 | 21.5 | 824.07 |
| 5 | 730.79 | 21.5 | 616.83 |
| 20 | 742.47 | 21.5 | 715.43 |

Representative $NO_x$ Concentration**: 741.03 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 37. Overall gas compositions: $NO_x$ test report No. R-7.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 8.2600 |
| $NO_x$ | 0.0000 | 0.0000 | 0.0741 |
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.9781 | 0.8966 |
| $O_2$ | 0.0000 | 11.3042 | 10.3621 |
| $N_2$ | 0.6398 | 81.7855 | 74.9694 |
| CO | 0.0000 | 0.0304 | 0.0279 |
| $CO_2$ | 0.0939 | 5.6370 | 5.1672 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0051 | 0.0047 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 89.8255 | 0.2400 | 0.2200 |
| $C_2$ | 9.1068 | 0.0197 | 0.0181 |
| $C_3$ | 0.3340 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.0000 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| $C_6$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 20.0204

Gross heating value of fuel gas = 41.19 $MJ/m^3$

= 950 MJ/kmole

(c) $NO_x$ Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.0741 \cdot 20.0204 \cdot 46.0055 \cdot 10^6}{100 \cdot 950}$$

$$= 719 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 51% lower than this EPA number.

2.1.7.5 Conclusions

The $NO_x$ emission factor for the tested reciprocating engine is 719 ng/J.

## 2.1.8 Natural Gas Fueled Engines: $NO_x$ Test Report No. R-8

Test Date: February 25, 1986
Test Location: Crossfield - South
Tested By: T. Seedhouse & C. Scott

### 2.1.8.1 Summary

A 820 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 218 ng/J was obtained. This is approximately 85% lower than the value of 1481 ng/J (55 400 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

### 2.1.8.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

### 2.1.8.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

### 2.1.8.4 Results

(1) Basic Data:

Field Work

Date: February 25, 1986
Location: Crossfield - South
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Cooper Bessemer
Model - GMVA-8
Rated Power Level - 820 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 7.0°C
Barometric Pressure: 671.58 mm Hg
Relative Humidity: 44%

Lab Work

Date: February 26, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 674.40 mm Hg

(2) Gas Analysis:

Table 38. Flue gas composition: $NO_x$ test report No. R-8.

| Component | Mole Percent Sample 1 | Sample 2 | Average Composition |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.9569 | 0.9572 | 0.9570 |
| $O_2$ | 15.8307 | 15.8454 | 15.8381 |
| $N_2$ | 80.0088 | 80.0377 | 80.0232 |
| $C_1$ | 0.2928 | 0.2810 | 0.2869 |
| CO | 0.0087 | 0.0091 | 0.0089 |
| $CO_2$ | 2.8741 | 2.8431 | 2.8586 |
| $C_2$ | 0.0265 | 0.0250 | 0.0258 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0015 | 0.0015 | 0.0015 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_5$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_5$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 39. Fuel gas composition: $NO_x$ test report No. R-8.

| Component | Mole Percent |
|---|---|
| $H_2$ | 0.0000 |
| Ar | 0.0000 |
| $O_2$ | 0.0000 |
| $N_2$ | 0.4684 |
| $C_1$ | 89.7300 |
| CO | 0.0000 |
| $CO_2$ | 0.0668 |
| $C_2$ | 9.2234 |
| $H_2S$ | 0.0000 |
| COS | 0.0000 |
| $C_3$ | 0.5103 |
| $SO_2$ | 0.0000 |
| $CS_2$ | 0.0000 |
| i-$C_4$ | 0.0007 |
| n-$C_4$ | 0.0004 |
| i-$C_5$ | 0.0000 |
| n-$C_5$ | 0.0000 |
| $C_6$+ | 0.0000 |
| | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.2022 $m^3$ |
| Meter Pressure - | 671.58 mm Hg |
| Meter Temperature - | 18.5°C |
| Impinger Pressure - | 608.08 mm Hg |
| Moles of Dried Flue Gas Metered - | 7.47 g - moles |
| Volume of $H_2O$ Condensed - | 5 ml |
| Moles of $H_2O$ Condensed - | 0.28 g - moles |
| Vapour Pressure of Drier - | 5.806 mm Hg |
| Moles of $H_2O$ Vapour - | 0.07 g - moles |
| Total Moles of Wet Flue Gas - | 7.82 g - moles |
| $H_2O$ Concentration - | 4.46 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 40. $NO_x$ determination - field data: $NO_x$ test report No. R-8.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 32 | 12:33 | 30 | 2004.0 | 67.06 | 671.58 | 7 |
| 35 | 12:36 | 30 | 2002.0 | 74.68 | 671.58 | 7 |
| 33 | 12:39 | 30 | 2008.0 | 81.03 | 671.58 | 7 |
| 10 | 13:23 | 30 | 2080.7 | 72.14 | 674.12 | 7 |
| 17 | 13:27 | 30 | 2102.8 | 73.41 | 671.58 | 7 |
| 12 | 13:30 | 30 | 2032.0 | 77.22 | 671.58 | 7 |

(b) Lab Data:

Table 41. $NO_x$ determination - lab data: $NO_x$ test report No. R-8.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 32 | 669.32 | 21.5 | 92.47 |
| 35 | 659.16 | 21.5 | 201.09 |
| 33 | 671.86 | 21.5 | 143.31 |
| 10 | 674.40 | 21.5 | 120.59 |
| 17 | 674.40 | 21.5 | 111.28 |
| 12 | 674.40 | 21.5 | 130.13 |

Representative $NO_x$ Concentration**: 126.33 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 42. Overall Gas Compositions: $NO_x$ test report No. R-8.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 4.4600 |
| $NO_x$ | 0.0000 | 0.0000 | 0.0126 |
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.9570 | 0.9142 |
| $O_2$ | 0.0000 | 15.8381 | 15.1297 |
| $N_2$ | 0.4684 | 80.0232 | 76.4441 |
| CO | 0.0000 | 0.0089 | 0.0085 |
| $CO_2$ | 0.0668 | 2.8586 | 2.7308 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 89.7300 | 0.2869 | 0.2741 |
| $C_2$ | 9.2234 | 0.0258 | 0.0246 |
| $C_3$ | 0.5103 | 0.0015 | 0.0014 |
| i-$C_4$ | 0.0007 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.0004 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| $C_6$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 35.79

Gross heating value of fuel gas = 40.39 $MJ/m^3$
= 955 MJ/kmole

(c) NOx Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.0126 \cdot 35.79 \cdot 46.0055 \cdot 10^6}{100 \cdot 955}$$

$$= 218 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 85% lower than this EPA number.

2.1.8.5 Conclusions

The $NO_x$ emission factor for the tested reciprocating engine is 218 ng/J.

## 2.1.9 Natural Gas Fueled Engines: $NO_x$ Test Report No. R-9

Test Date: February 27, 1986
Test Location: Harmatten Area
Tested By: T. Seedhouse & C. Scott

### 2.1.9.1 Summary

A 930 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 3412 ng/J was obtained. This is approximately 130% higher than the value of 1481 ng/J (55 400 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

### 2.1.9.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

### 2.1.9.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

### 2.1.9.4 Results

(1) Basic Data:

Field Work

Date: February 27, 1986
Location: Harmatten Area
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Ingersol Rand
Model - kVS (Turbo)
Rated Power Level - 930 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 6.0°C
Barometric Pressure: 664.97 mm Hg
Relative Humidity: 34%

Lab Work

Date: March 3, 1986
Location: Calgary
Ambient Temperature: 21.0°C
Barometric Pressure: 674.50 mm Hg

(2) Gas Analysis:

Table 43. Flue gas composition: $NO_x$ test report No. R-9.

| Component | Mole Percent Sample 1 | Sample 2 | Average Composition |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.9705 | 0.9773 | 0.9739 |
| $O_2$ | 12.4387 | 12.0597 | 12.2492 |
| $N_2$ | 81.1421 | 81.7128 | 81.4275 |
| $C_1$ | 0.2209 | 0.0326 | 0.1267 |
| CO | 0.0165 | 0.0175 | 0.0170 |
| $CO_2$ | 5.1869 | 5.2001 | 5.1935 |
| $C_2$ | 0.0232 | 0.0000 | 0.0116 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0012 | 0.0000 | 0.0006 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_5$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_5$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 44. Fuel gas composition: $NO_x$ test report No. R-9.

| Component | Mole Percent |
|---|---|
| $H_2$ | 0.0000 |
| Ar | 0.0000 |
| $O_2$ | 0.0000 |
| $N_2$ | 0.0892 |
| $C_1$ | 68.1466 |
| CO | 0.0000 |
| $CO_2$ | 6.9032 |
| $C_2$ | 23.6125 |
| $H_2S$ | 0.0000 |
| COS | 0.0000 |
| $C_3$ | 1.2307 |
| $SO_2$ | 0.0000 |
| $CS_2$ | 0.0000 |
| i-$C_4$ | 0.0051 |
| n-$C_4$ | 0.0036 |
| i-$C_5$ | 0.0052 |
| n-$C_5$ | 0.0039 |
| $C_6$+ | 0.0000 |
| | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.1546 $m^3$ |
| Meter Pressure - | 664.97 mm Hg |
| Meter Temperature - | 9.1°C |
| Impinger Pressure - | 614.17 mm Hg |
| Moles of Dried Flue Gas Metered - | 5.84 g - moles |
| Volume of $H_2O$ Condensed - | 10 ml |
| Moles of $H_2O$ Condensed - | 0.55 g - moles |
| Vapour Pressure of Drier - | 6.231 mm Hg |
| Moles of $H_2O$ Vapour - | 0.06 g - moles |
| Total Moles of Wet Flue Gas - | 6.46 g - moles |
| $H_2O$ Concentration - | 9.51 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 45. $NO_x$ determination - field data: $NO_x$ test report No. R-9.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 26 | 10:51 | 30 | 2020.0 | 69.37 | 664.97 | 6 |
| 27 | 10:54 | 30 | 2020.0 | 68.10 | 667.47 | 6 |
| 22 | 10:57 | 30 | 2024.7 | 68.10 | 664.97 | 6 |
| 30 | 11:36 | 30 | 2010.0 | 65.56 | 664.97 | 6 |
| 28 | 11:40 | 30 | 2001.0 | 60.48 | 664.97 | 6 |
| 23 | 11:43 | 30 | 1992.7 | 68.10 | 664.97 | 6 |

(b) Lab Data:

Table 46. $NO_x$ determination - lab data: $NO_x$ test report No. R-9.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 26 | 684.66 | 21.0 | 3059.33 |
| 27 | 674.50 | 21.0 | 2778.37 |
| 22 | 677.04 | 21.0 | 2949.89 |
| 30 | 674.50 | 21.0 | 3038.55 |
| 28 | 692.28 | 21.0 | 2657.34 |
| 23 | 684.66 | 21.0 | 2187.92 |

Representative $NO_x$ Concentration**: 2856.04 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 47. Overall gas compositions: $NO_x$ test report No. R-9.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 9.5100 |
| $NO_x$ | 0.0000 | 0.0000 | 0.2856 |
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.9739 | 0.8785 |
| $O_2$ | 0.0000 | 12.2492 | 11.0493 |
| $N_2$ | 0.0892 | 81.4275 | 73.4512 |
| CO | 0.0000 | 0.0170 | 0.0153 |
| $CO_2$ | 6.9032 | 5.1935 | 4.6847 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 68.1466 | 0.1267 | 0.1143 |
| $C_2$ | 23.6125 | 0.0116 | 0.0105 |
| $C_3$ | 1.2307 | 0.0006 | 0.0005 |
| i-$C_4$ | 0.0051 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.0036 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0052 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0039 | 0.0000 | 0.0000 |
| $C_6$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 26.0593

Gross heating value of fuel gas = 42.46 $MJ/m^3$
= 1003 MJ/kmole

(c) $NO_x$ Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.2856 \cdot 26.0593 \cdot 46.0055 \cdot 10^6}{100 \cdot 1003}$$

$$= 3412 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 130% higher than this EPA number.

2.1.9.5 Conclusions

The $NO_x$ emission factor for the tested reciprocating engine is 3412 ng/J.

## 2.1.10 Natural Gas Fueled Engines: $NO_x$ Test Report No. R-10

Test Date: February 27, 1986
Test Location: Harmatten Area
Tested By: T. Seedhouse & C. Scott

### 2.1.10.1 Summary

A 1500 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 2554 ng/J was obtained. This is approximately 72% higher than the value of 1481 ng/J (55 400 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

### 2.1.10.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

### 2.1.10.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

### 2.1.10.4 Results

(1) Basic Data:

Field Work

Date: February 27, 1986
Location: Harmatten Area
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Ingersol Rand
Model - kVS (Turbo)
Rated Power Level - 1500 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 7.0°C
Barometric Pressure: 664.97 mm Hg
Relative Humidity: 34%

Lab Work

Date: March 3, 1986
Location: Calgary
Ambient Temperature: 21.0°C
Barometric Pressure: 674.5 mm Hg

(2) Gas Analysis:

Table 48. Flue gas composition: $NO_x$ test report No. R-10.

| Component | Mole Percent Sample 1 | Sample 2 | Average Composition |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.9879 | 0.9854 | 0.9867 |
| $O_2$ | 8.3292 | 9.2148 | 8.7720 |
| $N_2$ | 82.5981 | 82.3882 | 82.4932 |
| $C_1$ | 0.2030 | 0.1889 | 0.1959 |
| CO | 0.0169 | 0.0162 | 0.0165 |
| $CO_2$ | 7.7925 | 7.1453 | 7.4689 |
| $C_2$ | 0.0690 | 0.0580 | 0.0635 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0034 | 0.0032 | 0.0033 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_5$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_5$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 49. Fuel gas composition: $NO_x$ test report No. R-10.

| Component | Mole Percent |
|---|---|
| $H_2$ | 0.0000 |
| Ar | 0.0000 |
| $O_2$ | 0.0000 |
| $N_2$ | 0.0892 |
| $C_1$ | 68.1466 |
| CO | 0.0000 |
| $CO_2$ | 6.9032 |
| $C_2$ | 23.6125 |
| $H_2S$ | 0.0000 |
| COS | 0.0000 |
| $C_3$ | 1.2307 |
| $SO_2$ | 0.0000 |
| $CS_2$ | 0.0000 |
| i-$C_4$ | 0.0051 |
| n-$C_4$ | 0.0036 |
| i-$C_5$ | 0.0052 |
| n-$C_5$ | 0.0039 |
| $C_6$+ | 0.0000 |
| | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.1788 $m^3$ |
| Meter Pressure - | 664.97 mm Hg |
| Meter Temperature - | 24.3°C |
| Impinger Pressure - | 614.17 mm Hg |
| Moles of Dried Flue Gas Metered - | 6.41 g - moles |
| Volume of $H_2O$ Condensed - | 11 ml |
| Moles of $H_2O$ Condensed - | 0.61 g - moles |
| Vapour Pressure of Drier - | 8.611 mm Hg |
| Moles of $H_2O$ Vapour - | 0.09 g - moles |
| Total Moles of Wet Flue Gas - | 7.11 g - moles |
| $H_2O$ Concentration - | 9.85 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 50. $NO_x$ determination - field data: $NO_x$ test report No. R-10.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 4 | 12:18 | 30 | 2105.2 | 57.73 | 664.97 | 7 |
| 18 | 12:21 | 30 | 2041.2 | 42.49 | 664.97 | 7 |
| 32 | 12:24 | 30 | 2004.0 | 43.76 | 664.97 | 7 |
| 33 | 13:02 | 30 | 2008.0 | 34.87 | 670.05 | 7 |
| 17 | 13:07 | 30 | 2102.8 | 41.22 | 664.97 | 7 |
| 10 | 13:09 | 30 | 2080.7 | 47.57 | 667.51 | 7 |

(b) Lab Data:

Table 51. $NO_x$ determination - lab data: $NO_x$ test report No. R-10.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 4 | 664.34 | 21.0 | 2854.55 |
| 18 | 674.50 | 21.0 | 3273.47 |
| 32 | 659.26 | 21.0 | 3075.96 |
| 33 | 649.10 | 21.0 | 2868.85 |
| 17 | 659.26 | 21.0 | 3389.89 |
| 10 | 674.50 | 21.0 | 3195.92 |

Representative $NO_x$ Concentration**: 3103.55 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 52. Overall gas compositions: $NO_x$ test report No. R-10.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 9.8500 |
| $NO_x$ | 0.0000 | 0.0000 | 0.3104 |
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.9867 | 0.8865 |
| $O_2$ | 0.0000 | 8.7720 | 7.8807 |
| $N_2$ | 0.0892 | 82.4932 | 74.1116 |
| CO | 0.0000 | 0.0165 | 0.0148 |
| $CO_2$ | 6.9032 | 7.4689 | 6.7100 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 68.1466 | 0.1959 | 0.1760 |
| $C_2$ | 23.6125 | 0.0635 | 0.0570 |
| $C_3$ | 1.2307 | 0.0033 | 0.0030 |
| i-$C_4$ | 0.0051 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.0036 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0052 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0039 | 0.0000 | 0.0000 |
| $C_6$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 17.9456

Gross heating value of fuel gas = 42.46 $MJ/m^3$
= 1003 MJ/kmole

(c) $NO_x$ Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.3104 \cdot 17.9456 \cdot 46.0055 \cdot 10^6}{100 \cdot 1003}$$

$$= 2554 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 72% higher than this EPA number.

2.1.10.5 Conclucions

The $NO_x$ emission factor for the tested reciprocating engine is 2554 ng/J.

## 2.1.11 Natural Gas Fueled Engines: $NO_x$ - Test Report No. R-11

Test Date: February 27, 1986
Test Location: Harmatten Area
Tested By: T. Seedhouse & C. Scott

### 2.1.11.1 Summary

A 1120 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 1341 ng/J was obtained. This is approximately 9% lower than the value of 1481 ng/J (55 400 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

### 2.1.11.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

### 2.1.11.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

### 2.1.11.4 Results

(1) Basic Data:

Field Work

Date: February 27, 1986
Location: Harmatten Area
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Ingersol Rand
Model - kVGB
Rated Power Level - 1120 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 12.0°C
Barometric Pressure: 664.97 mm Hg
Relative Humidity: 34%

Lab Work

Date: March 3, 1986
Location: Calgary
Ambient Temperature: 21.0°C
Barometric Pressure: 674.50 mm Hg

(2) Gas Analysis:

Table 53. Flue gas composition: $NO_x$ test report No. R-11.

| Component | Mole Percent Sample 1 | Sample 2 | Average Composition |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.9826 | 0.9875 | 0.9850 |
| $O_2$ | 6.7350 | 5.6206 | 6.1778 |
| $N_2$ | 82.1539 | 82.5712 | 82.3626 |
| $C_1$ | 0.7469 | 0.7909 | 0.7689 |
| CO | 0.0127 | 0.0191 | 0.0159 |
| $CO_2$ | 9.0805 | 9.7036 | 9.3920 |
| $C_2$ | 0.2733 | 0.2908 | 0.2821 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0151 | 0.0164 | 0.0157 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_5$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_5$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 54. Fuel gas composition: $NO_x$ test report No. R-11.

| Component | Mole Percent |
|---|---|
| $H_2$ | 0.0000 |
| Ar | 0.0000 |
| $O_2$ | 0.0000 |
| $N_2$ | 0.0892 |
| $C_1$ | 68.1466 |
| CO | 0.0000 |
| $CO_2$ | 6.9032 |
| $C_2$ | 23.6125 |
| $H_2S$ | 0.0000 |
| COS | 0.0000 |
| $C_3$ | 1.2307 |
| $SO_2$ | 0.0000 |
| $CS_2$ | 0.0000 |
| i-$C_4$ | 0.0051 |
| n-$C_4$ | 0.0036 |
| i-$C_5$ | 0.0052 |
| n-$C_5$ | 0.0039 |
| $C_6$+ | 0.0000 |
| | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.1883 $m^3$ |
| Meter Pressure - | 664.97 mm Hg |
| Meter Temperature - | 26.7°C |
| Impinger Pressure - | 614.17 mm Hg |
| Moles of Dried Flue Gas Metered - | 6.70 g - moles |
| Volume of $H_2O$ Condensed - | 15 ml |
| Moles of $H_2O$ Condensed - | 0.83 g - moles |
| Vapour Pressure of Drier - | 6.5430 mm Hg |
| Moles of $H_2O$ Vapour - | 0.07 g - moles |
| Total Moles of Wet Flue Gas - | 7.60 g - moles |
| $H_2O$ Concentration - | 11.88 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 55. $NO_x$ determination - field data: $NO_x$ test report No. R-11.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 2 | 13:36 | 30 | 2105.2 | 43.94 | 664.97 | 12 |
| 5 | 13:39 | 30 | 2041.5 | 35.05 | 664.97 | 12 |
| 20 | 13:42 | 30 | 2079.9 | 35.05 | 664.97 | 12 |
| 35 | 14:20 | 30 | 2002.0 | 52.83 | 664.97 | 12 |
| 15 | 14:23 | 30 | 2027.3 | 68.07 | 664.97 | 12 |
| Broken | - | - | - | - | - | - |

(b) Lab Data:

Table 56. $NO_x$ determination - lab data: $NO_x$ test report No. R-11.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 2 | 649.10 | 21.0 | 3016.95 |
| 5 | 654.18 | 21.0 | 2797.97 |
| 20 | 608.46 | 21.0 | 2716.05 |
| 35 | 661.80 | 21.0 | 3493.27 |
| 15 | 664.34 | 21.0 | 2989.28 |
| - | - | - | - |

Representative $NO_x$ Concentration**: 2201.05 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 57. Overall gas compositions: $NO_x$ test report No. R-11.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 11.8800 |
| $NO_x$ | 0.0000 | 0.0000 | 0.2201 |
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.9850 | 0.8658 |
| $O_2$ | 0.0000 | 6.1778 | 5.4303 |
| $N_2$ | 0.0892 | 82.3626 | 72.3966 |
| CO | 0.0000 | 0.0159 | 0.0140 |
| $CO_2$ | 6.9032 | 9.3920 | 8.2556 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 68.1466 | 0.7689 | 0.6759 |
| $C_2$ | 23.6125 | 0.2821 | 0.2480 |
| $C_3$ | 1.2307 | 0.0157 | 0.0138 |
| i-$C_4$ | 0.0051 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.0036 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0052 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0039 | 0.0000 | 0.0000 |
| $C_6$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 13.2923

Gross heating value of fuel gas = 42.46 $MJ/m^3$
= 1003 MJ/kmole

(c) $NO_x$ Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.2201 \cdot 13.2923 \cdot 46.0055 \cdot 10^6}{100 \cdot 1003}$$

$$= 1341 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 9% lower than this EPA number.

2.1.11.5 Conclusions

The $NO_x$ emission factor for the tested reciprocating engine is 1341 ng/J.

## 2.1.12 Natural Gas Fueled Engines: $NO_x$ Test Report No. R-12

Test Date: February 27, 1986
Test Location: Harmatten Area
Tested By: T. Seedhouse & C. Scott

### 2.1.12.1 Summary

A 1120 kW natural gas fueled reciprocating engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 504 ng/J was obtained. This is approximately 66% lower than the value of 1481 ng/J (55 400 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

### 2.1.12.2 Introduction

See Report R-1 (i.e., Section 2.1.1.2).

### 2.1.12.3 Procedure

See Report R-1 (i.e., Section 2.1.1.3).

### 2.1.12.4 Results

(1) Basic Data:

Field Work

Date: February 27, 1986
Location: Harmatten Area
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Ingersol Rand
Model - kVGR
Rated Power Level - 1120 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 7.0°C
Barometric Pressure: 664.97 mm Hg
Relative Humidity: 34%

Lab Work

Date: March 3, 1986
Location: Calgary
Ambient Temperature: 21.0°C
Barometric Pressure: 674.50 mm Hg

(2) Gas Analysis:

Table 58. Flue gas composition: $NO_x$ test report No. R-12.

| Component | Mole Percent Sample 1 | Sample 2 | Average Composition |
|---|---|---|---|
| $H_2$ | 0.8683 | 1.3162 | 1.0922 |
| Ar | 0.9857 | 1.0012 | 0.9934 |
| $O_2$ | 5.9938 | 1.9344 | 3.9641 |
| $N_2$ | 82.4134 | 83.7129 | 83.0632 |
| $C_1$ | 0.0353 | 0.0090 | 0.0222 |
| CO | 1.7241 | 2.1823 | 1.9532 |
| $CO_2$ | 7.9776 | 9.8440 | 8.9108 |
| $C_2$ | 0.0018 | 0.0000 | 0.0009 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_4$ | 0.0000 | 0.0000 | 0.0000 |
| $iC_5$ | 0.0000 | 0.0000 | 0.0000 |
| $nC_5$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 59. Fuel gas composition: $NO_x$ test report No. R-12.

| Component | Mole Percent |
|---|---|
| $H_2$ | 0.0000 |
| Ar | 0.0000 |
| $O_2$ | 0.0000 |
| $N_2$ | 1.1044 |
| $C_1$ | 85.9195 |
| CO | 0.0000 |
| $CO_2$ | 0.0184 |
| $C_2$ | 11.9428 |
| $H_2S$ | 0.0000 |
| COS | 0.0000 |
| $C_3$ | 0.9762 |
| $SO_2$ | 0.0000 |
| $CS_2$ | 0.0000 |
| i-$C_4$ | 0.0152 |
| n-$C_4$ | 0.0079 |
| i-$C_5$ | 0.0087 |
| n-$C_5$ | 0.0069 |
| $C_6$+ | 0.0000 |
| | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.1713 $m^3$ |
| Meter Pressure - | 664.97 mm Hg |
| Meter Temperature - | 29.4°C |
| Impinger Pressure - | 614.17 mm Hg |
| Moles of Dried Flue Gas Metered - | 6.04 g - moles |
| Volume of $H_2O$ Condensed - | 20 ml |
| Moles of $H_2O$ Condensed - | 1.11 g - moles |
| Vapour Pressure of Drier - | 8.611 mm Hg |
| Moles of $H_2O$ Vapour - | 0.09 g - moles |
| Total Moles of Wet Flue Gas - | 7.23 g - moles |
| $H_2O$ Concentration - | 16.51 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 60. $NO_x$ determination - field data: $NO_x$ test report No. R-12.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 6 | 14:37 | 30 | 2033.4 | 60.45 | 664.97 | 7 |
| 34 | 14:40 | 30 | 2003.0 | 57.91 | 664.97 | 7 |
| 11 | 14:42 | 30 | 2086.6 | 57.91 | 664.97 | 7 |
| 8 | 15:18 | 30 | 2067.5 | 57.91 | 664.97 | 7 |
| 3 | 15:20 | 30 | 2054.3 | 68.07 | 664.97 | 7 |
| 9 | 15:22 | 30 | 2038.4 | 68.07 | 664.97 | 7 |

(b) Lab Data:

Table 61. $NO_x$ determination - lab data: $NO_x$ test report No. R-12.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 6 | 679.58 | 21.0 | 849.54 |
| 34 | 677.04 | 21.0 | 857.33 |
| 11 | 674.50 | 21.0 | 820.97 |
| 8 | 656.72 | 21.0 | 884.10 |
| 3 | 674.50 | 21.0 | 846.27 |
| 9 | 674.50 | 21.0 | 901.73 |

Representative $NO_x$ Concentration**: 859.31 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 62. Overall gas compositions: $NO_x$ test report No. R-12.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 16.5100 |
| $NO_x$ | 0.0000 | 0.0000 | 0.0859 |
| $H_2$ | 0.0000 | 1.0922 | 0.9109 |
| Ar | 0.0000 | 0.9934 | 0.8285 |
| $O_2$ | 0.0000 | 3.9641 | 3.3062 |
| $N_2$ | 1.1044 | 83.0632 | 69.2781 |
| CO | 0.0000 | 1.9532 | 1.6290 |
| $CO_2$ | 0.0184 | 8.9108 | 7.4320 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 85.9195 | 0.0222 | 0.0185 |
| $C_2$ | 11.9428 | 0.0009 | 0.0008 |
| $C_3$ | 0.9762 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.0152 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.0079 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0087 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0069 | 0.0000 | 0.0000 |
| $C_6$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 12.4350

Gross heating value of fuel gas = 41.24 $MJ/m^3$
= 975 MJ/kmole

(c) $NO_x$ Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.0859 \cdot 12.4350 \cdot 46.0055 \cdot 10^6}{100 \cdot 975}$$

$$= 504 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled reciprocating engines is 1481 ng/J. The value obtained here is approximately 66% lower than this EPA number.

2.1.12.5 Conclusions

The $NO_x$ emission factor for the tested reciprocating engine is 504 ng/J.

## 2.2 INDIVIDUAL REPORTS FOR THE SURVEYED TURBINE ENGINES

The individual reports prepared for each of the six turbine engines surveyed are presented in the following. Since the Introduction and Procedure sections of each report are basically the same, these have been omitted from all but the first report to avoid repetition.

## 2.2.1 Natural Gas Fueled Engines: $NO_x$ Test Report No. T-1

Test Date: November 14, 1985
Test Location: Cochrane Area
Tested By: R. Tamura & D. Picard

### 2.2.1.1 Summary

A 18 540 kW natural gas fueled turbine engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 124.2 ng/J was obtained. This agrees well with the value of 126 ng/J (4700 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled turbine engines.

### 2.2.1.2 Introduction

In Alberta, the primary industrial source of $NO_x$ emissions is the internal combustion engine (i.e., large turbine and reciprocating engines). The amount of $NO_x$ emitted from these units is normally estimated using emission factors. Emission factors express $NO_x$ emissions in terms of nanograms per joule of fuel consumed (ng/J).

Production of $NO_x$ is a complex process. Ambient temperature, pressure and humidity, and operating conditions are all known to have a significant effect. Subsequently, the use of emission factors provides only a rough approximation of actual emissions. In order to obtain $NO_x$ emission factors that will best approximate $NO_x$ emissions in Alberta, a number of representative emission sources are being tested (Alberta-specific emission factors are not currently available).

In Alberta, the vast majority of industrial turbine and reciprocating engines are natural gas fueled. Therefore only natural gas fueled engines are being considered.

A minimum of six turbine engines and six reciprocating engines of various power levels will be tested. In this report $NO_x$ testing of a 18 540 kW turbine engine is discussed.

2.2.1.3 Procedure

(1) The following basic data were recorded:

- location,
- date,
- ambient temperature,
- relative humidity,
- barometric pressure,
- test crew, and
- test unit description.

(2) Duplicate samples of both the fuel and flue gases were collected and subsequently analyzed by a gas chromatograph. These analyses were used to obtain a single representative $NO_x$ and $H_2O$ free composition of both the fuel and flue gases.

(3) The moisture content of the flue gas was determined using a half hour condensation test as described under Method 3 in the Alberta Environment Stack Sampling Code (1976).

Any natural gas mixture supplied as fuel to an internal combustion engine will contain much less than 1% $H_2O$. Moisture levels of this magnitude are insignificant in terms of calculating $NO_x$ emission factors. Therefore, moisture content of the fuel gas was not determined.

(4) The $NO_x$ content of the flue gas was determined using the $NO_x$ testing procedure described under Method 6 in the Alberta Environment Stack Sampling Code (1976). Two triplicate tests were performed (i.e., 6 $NO_x$ samples were taken). Results of these tests were used to obtain a single representative $NO_x$ concentration for the flue gas.

(5) Using the results of (2), (3) and (4) an overall representative composition was determined for the flue gas. The overall reaction for the combustion process is expressed as:

$$\begin{bmatrix}\text{Overall}\\ \text{Fuel Gas}\\ \text{Composition}\end{bmatrix} + a \begin{bmatrix}\text{Overall}\\ \text{Composition}\\ \text{of the Air}\end{bmatrix} \rightarrow b \begin{bmatrix}\text{Overall}\\ \text{Flue Gas}\\ \text{Composition}\end{bmatrix} \qquad (1)$$

where "a" and "b" are stoichiometric coefficients. If it is assumed that the concentration of carbon compounds is negligible in the air then the coefficient "b" may be obtained by balancing the carbon atoms between the fuel gas and the flue gas compositions.

An analysis of the air was not conducted nor was "a" evaluated, as this information was not required.

The $NO_x$ emission factor was calculated using the following equation:

$$EF = \frac{y\,(NO_x) \cdot b \cdot M\,(NO_2) \cdot g_c}{\text{100 kmoles of fuel gas} \cdot \Delta H} \qquad (2)$$

where,

EF = $NO_x$ emission factor, ng of $NO_x$/J of fuel gas

y ($NO_x$) = mole percent of $NO_x$ expressed as an $NO_2$ equivalent

M ($NO_2$) = molecular weight of $NO_2$
= 46.0055 kg/kmole

$g_c$ = conversion factor
= $10^6$

$\Delta H$ = gross heat value of the fuel gas, MJ/kmole

2.2.1.4 Results

(1) Basic Data:

Field Work

Date: November 14, 1985
Location: Cochrane Area
Test Crew: R. Tamura & D. Picard

Test Unit: Make - General Electric
Model - 5332 B
Rated Power Level - 18 540 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 3°C
Barometric Pressure: 653.03 mm Hg
Relative Humidity: 26%

Lab Work

Date: December 4, 1985
Location: Calgary
Ambient Temperature: 22°C
Barometric Pressure: 669.60 mm Hg

(2) Gas Analysis:

Table 63. Flue gas composition: $NO_x$ test report No. T-1.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.9586 | 0.9590 | 0.9588 |
| $O_2$ | 16.0669 | 16.0030 | 16.0350 |
| $N_2$ | 80.1543 | 80.1804 | 80.1673 |
| $C_1$ | 0.0000 | 0.0000 | 0.0000 |
| CO | 0.0022 | 0.0026 | 0.0024 |
| $CO_2$ | 2.8180 | 2.8550 | 2.8365 |
| $C_2$ | 0.0000 | 0.0000 | 0.0000 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 64. Fuel gas composition: $NO_x$ test report No. T-1.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.0000 | 0.0000 |
| $O_2$ | 0.0000 | 0.0000 | 0.0000 |
| $N_2$ | 1.2214 | 1.1940 | 1.2077 |
| $C_1$ | 97.2356 | 97.2630 | 97.2493 |
| CO | 0.0000 | 0.0000 | 0.0000 |
| $CO_2$ | 0.3111 | 0.3097 | 0.3104 |
| $C_2$ | 1.2143 | 1.2158 | 1.2151 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0176 | 0.0175 | 0.0175 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.0000 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| $C_6$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.1696 $m^3$ |
| Meter Pressure - | 653.03 mm Hg |
| Meter Temperature - | 11.6°C |
| Impinger Pressure - | 627.63 mm Hg |
| Moles of Dried Flue Gas Metered - | 6.24 g - moles |
| Volume of $H_2O$ Condensed - | 5 ml |
| Moles of $H_2O$ Condensed - | 0.28 g - moles |
| Vapour Pressure of Drier - | 6.543 mm Hg |
| Moles of $H_2O$ Vapour - | 0.07 g - moles |
| Total Moles of Wet Flue Gas - | 6.58 g - moles |
| $H_2O$ Concentration - | 5.21 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 65. $NO_x$ determination - field data: $NO_x$ test report No. T-1.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 27 | 10:22 | 30 | 2020.0 | 56.13 | 653.03 | 3 |
| 26 | 10:24 | 30 | 2020.0 | 56.13 | 650.49 | 3 |
| 28 | 10:26 | 30 | 2001.0 | 56.13 | 650.49 | 3 |
| 23 | 11:42 | 30 | 1992.7 | 56.13 | 650.49 | 3 |
| 22 | 11:45 | 30 | 2024.7 | 56.13 | 650.49 | 3 |
| 9A | 11:47 | 30 | 2038.4 | 56.13 | 653.03 | 3 |

(b) Lab Data:

Table 66. $NO_x$ determination - lab data: $NO_x$ test report No. 1-1.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 27 | 667.06 | 22 | 52.94 |
| 26 | 669.60 | 22 | 64.28 |
| 28 | 679.76 | 22 | 67.66 |
| 23 | 684.84 | 22 | 67.94 |
| 22 | 669.60 | 22 | 164.28 |
| 9A | 689.92 | 22 | 57.41 |

Representative $NO_x$ Concentration*: 64.32 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas both the high and low values were discarded and an average was taker of the remaining 4 readings. Condensation in the sample tubes may have been the cause for the abnormally large $NO_x$ concentration for flask 22.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 67. Overall gas compositions: $NO_x$ test report No. T-1.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 5.2100 |
| $NO_x$ | 0.0000 | 0.0000 | 0.0064 |
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.9588 | 0.9088 |
| $O_2$ | 0.0000 | 16.0350 | 15.1985 |
| $N_2$ | 1.2077 | 80.1673 | 75.9854 |
| CO | 0.0000 | 0.0024 | 0.0023 |
| $CO_2$ | 0.3104 | 2.8365 | 2.6885 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 97.2493 | 0.0000 | 0.0000 |
| $C_2$ | 1.2151 | 0.0000 | 0.0000 |
| $C_3$ | 0.0175 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.0000 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0000 | 0.0000 | 0.0000 |
| $C_6$ | 0.0000 | 0.0000 | 0.0000 |
| $C_7$+ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 37.1793

Gross heating value of fuel gas = 37.48 $MJ/m^3$

= 885 MJ/kmole

(c) $NO_x$ Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.006432 \cdot 37.1793 \cdot 46.0055 \cdot 10^6}{100 \cdot 885}$$

$$= 124.2 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled turbine engines is 126 ng/J. The value obtained here is approximately 1.4% less than this EPA number.

2.2.1.5 Conclusions

The $NO_x$ emission factor for the tested turbine engine is 124.2.

## 2.2.2 · Natural Gas Fueled Engines: $NO_x$ Test Report No. T-2

Test Date: December 10, 1985
Test Location: Clearwater Area
Tested By: R. Tamura & M. Towill

### 2.2.2.1 Summary

A 17 310 kW natural gas fueled turbine engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 122.9 ng/J was obtained. This is approximately 2% lower than the value of 126 ng/J (4700 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

### 2.2.2.2 Introduction

See Report T-1 (i.e., Section 2.2.1.2).

### 2.2.2.3 Procedure

See Report T-1 (i.e., Section 2.2.1.3).

### 2.2.2.4 Results

(1) Basic Data:

Field Work

Date: December 10, 1985
Location: Clearwater Area
Test Crew: R. Tamura & M. LaCoste

Test Unit: Make - General Electric
Model - 7LM
Rated Power Level - 17 310 kW
Service - Driver for a natural gas compressor

Ambient Temperature: -10°C
Barometric Pressure: 680.72 mm Hg
Relative Humidity: 62%

Lab Work

Date: December 16, 1985
Location: Calgary
Ambient Temperature: 23°C
Barometric Pressure: 703.33 mm Hg

(2) Gas Analysis:

Table 68. Flue gas composition: $NO_x$ test report No. T-2.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.9420 | 0.9422 | 0.9421 |
| $O_2$ | 19.8577 | 19.8410 | 19.8493 |
| $N_2$ | 78.7584 | 78.7759 | 78.7672 |
| $C_1$ | 0.0000 | 0.0000 | 0.0000 |
| CO | 0.0021 | 0.0014 | 0.0018 |
| $CO_2$ | 0.4398 | 0.4395 | 0.4396 |
| $C_2$ | 0.0000 | 0.0000 | 0.0000 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 69. Fuel gas composition: $NO_x$ test report No. T-2.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.0000 | 0.0000 |
| $O_2$ | 0.0000 | 0.0000 | 0.0000 |
| $N_2$ | 0.6735 | 0.6851 | 0.6793 |
| $C_1$ | 91.9135 | 91.8443 | 91.8796 |
| CO | 0.0000 | 0.0000 | 0.0000 |
| $CO_2$ | 0.5749 | 0.5880 | 0.5814 |
| $C_2$ | 5.4171 | 5.4356 | 5.4263 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 1.0494 | 1.0486 | 1.0490 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.1284 | 0.1298 | 0.1291 |
| n-$C_4$ | 0.1935 | 0.1963 | 0.1949 |
| i-$C_5$ | 0.0152 | 0.0357 | 0.0254 |
| n-$C_5$ | 0.0291 | 0.0301 | 0.0296 |
| $C_6$ | 0.0054 | 0.0065 | 0.0060 |
| | 100.0000 | 100.0000 | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.1435 $m^3$ |
| Meter Pressure - | 680.70 mm Hg |
| Meter Temperature - | 10°C |
| Impinger Pressure - | 607.67 mm Hg |
| Moles of Dried Flue Gas Metered - | 5.53 g - moles |
| Volume of $H_2O$ Condensed - | 4 ml |
| Moles of $H_2O$ Condensed - | 0.22 g - moles |
| Vapour Pressure of Drier - | 4.582 mm Hg |
| Moles of $H_2O$ Vapour - | 0.04 g - moles |
| Total Moles of Wet Flue Gas - | 5.80 g - moles |
| $H_2O$ Concentration - | 4.55 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 70. $NO_x$ determination - field data: $NO_x$ test report No. T-2.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 11 | 12:00 | 30 | 2086.60 | 53.32 | 617.20 | -10 |
| 3 | 12:02 | 30 | 2054.30 | 48.22 | 551.16 | -10 |
| 18 | 12:04 | 30 | 2041.20 | 53.32 | 617.20 | -10 |
| 9 | 13:14 | 30 | 2038.40 | 66.02 | 551.16 | -10 |
| 5 | 13:16 | 30 | 2041.50 | 66.02 | 551.16 | -10 |
| 20 | 13:18 | 30 | 2079.90 | 66.02 | 680.70 | -10 |

(b) Lab Data:

Table 71. $NO_x$ determination - lab data: $NO_x$ test report No. T-2.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 11 | 645.16 | 23 | 92.09 |
| 3 | 452.12 | 23 | 83.60 |
| 18 | 581.66 | 23 | 4.33 |
| 9 | 774.70 | 23 | 9.86 |
| 5 | 515.62 | 23 | 10.83 |
| 20 | 708.66 | 23 | 8.62 |

Representative $NO_x$ Concentration*: 9.77 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas both the high and low values were discarded (i.e., flasks 11 and 18) and so was flask 3 since it was noteably larger than the remaining values. Condensation in the sample tubes may have been the cause for the two abnormally large $NO_x$ concentrations.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 72. Overall gas compositions: $NO_x$ test report No. T-2.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 4.5500 |
| $NO_x$ | 0.0000 | 0.0000 | 0.0010 |
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.9421 | 0.8992 |
| $O_2$ | 0.0000 | 19.8493 | 18.9460 |
| $N_2$ | 0.6793 | 78.7672 | 75.1825 |
| CO | 0.0000 | 0.0018 | 0.0017 |
| $CO_2$ | 0.5814 | 0.4396 | 0.4196 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 91.8790 | 0.0000 | 0.0000 |
| $C_2$ | 5.4263 | 0.0000 | 0.0000 |
| $C_3$ | 1.0490 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.1291 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.1949 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0254 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0296 | 0.0000 | 0.0000 |
| $C_6$ | 0.0060 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

b) Other Information:

Stoichiometric Coefficient "b" = 256.50

Gross heating value of fuel gas = 39.69 $MJ/m^3$

= 938 MJ/kmole

(c) $NO_x$ Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.000977 \cdot 256.50 \cdot 46.0055 \cdot 10^6}{100 \cdot 938}$$

$$= 122.9 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled turbine engines is 126 ng/J. The value obtained here is approximately 2.46% less than this EPA number.

2.2.2.5 Conclusions

The $NO_x$ emission factor for the tested turbine engine is 122.9 ng/J.

## 2.2.3 · Natural Gas Fueled Engines: $NO_x$ Test Report No. T-3

Test Date: January 6, 1986
Test Location: Burton Creek Area
Tested By: T. Seedhouse & B. Reshetylo

### 2.2.3.1 Summary

A 9 025 kW natural gas fueled turbine engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 46.8 ng/J was obtained. This is approximately 63% lower than the value of 126 ng/J (4700 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

### 2.2.3.2 Introduction

See Report T-1 (i.e., Section 2.2.1.2).

### 2.2.3.3 Procedure

See Report T-1 (i.e, Section 2.2.1.3).

### 2.2.3.4 Results

(1) Basic Data:

Field Work

Date: January 6, 1986
Location: Burton Creek Area
Test Crew: T. Seedhouse & B. Reshetylo

Test Unit: Make - Cooper - Bessemer
Model - RT48
Rated Power Level - 9 025 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 7°C
Barometric Pressure: 687.07 mm Hg
Relative Humidity: 50%

Lab Work

Date: January 8, 1986
Location: Calgary
Ambient Temperature: 22°C
Barometric Pressure: 665.23 mm Hg

(2) Gas Analysis:

Table 73. Flue gas composition: $NO_x$ test report No. T-3.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.9360 | 0.9354 | 0.9357 |
| $O_2$ | 19.5505 | 19.5600 | 19.5553 |
| $N_2$ | 78.2590 | 78.2098 | 78.2344 |
| $C_1$ | 0.0666 | 0.0773 | 0.0719 |
| CO | 0.0245 | 0.0243 | 0.0244 |
| $CO_2$ | 1.1634 | 1.1932 | 1.1783 |
| $C_2$ | 0.0000 | 0.0000 | 0.0000 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 74. Fuel gas composition: $NO_x$ test report No. T-3.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.0000 | 0.0000 |
| $O_2$ | 0.0000 | 0.0000 | 0.0000 |
| $N_2$ | 1.0914 | 1.1061 | 1.0987 |
| $C_1$ | 97.4524 | 97.4396 | 97.4460 |
| CO | 0.0000 | 0.0000 | 0.0000 |
| $CO_2$ | 0.2674 | 0.2628 | 0.2651 |
| $C_2$ | 1.1439 | 1.1444 | 1.1441 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0389 | 0.0392 | 0.0390 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.0018 | 0.0021 | 0.0020 |
| n-$C_4$ | 0.0034 | 0.0037 | 0.0036 |
| i-$C_5$ | 0.0004 | 0.0011 | 0.0008 |
| n-$C_5$ | 0.0005 | 0.0010 | 0.0007 |
| $C_6$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.1557 $m^3$ |
| Meter Pressure - | 687.07 mm Hg |
| Meter Temperature - | 20.7°C |
| Impinger Pressure - | 636.27 mm Hg |
| Moles of Dried Flue Gas Metered - | 5.84 g - moles |
| Volume of $H_2O$ Condensed - | 4 ml |
| Moles of $H_2O$ Condensed - | 0.22 g - moles |
| Vapour Pressure of Drier - | 8.494 mm Hg |
| Moles of $H_2O$ Vapour - | 0.08 g - moles |
| Total Moles of Wet Flue Gas - | 6.14 g - moles |
| $H_2O$ Concentration - | 4.90 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 75. $NO_x$ determination - field data: $NO_x$ test report No. T-3.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 28 | 12:12 | 30 | 2001.0 | 97.79 | 687.07 | 5 |
| 9A | 12:15 | 30 | 2038.4 | 97.79 | 687.07 | 5 |
| 23 | 12:18 | 30 | 1992.7 | 97.79 | 687.07 | 5 |
| 26 | 13:04 | 30 | 2020.0 | 97.79 | 687.07 | 5 |
| 22 | 13:07 | 30 | 2024.7 | 85.09 | 687.07 | 5 |
| 27 | 13:10 | 30 | 2020.0 | 95.25 | 687.07 | 5 |

(b) Lab Data:

Table 76. $NO_x$ determination - lab data: $NO_x$ test report No. T-3.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 28 | 660.15 | 22 | 10.71 |
| 9A | 665.23 | 22 | 11.15 |
| 23 | 657.61 | 22 | 11.31 |
| 26 | 652.53 | 22 | 9.01 |
| 22 | 642.37 | 22 | 10.92 |
| 27 | 644.91 | 22 | 10.85 |

Representative $NO_x$ Concentration*: 10.91 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 77. Overall gas compositions: $NO_x$ test report No. T-3.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 4.9000 |
| $NO_x$ | 0.0000 | 0.0000 | 0.0011 |
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.9357 | 0.8898 |
| $O_2$ | 0.0000 | 19.5553 | 18.5969 |
| $N_2$ | 1.0987 | 78.2344 | 74.4000 |
| CO | 0.0000 | 0.0244 | 0.0232 |
| $CO_2$ | 0.2651 | 1.1783 | 1.1206 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 97.4460 | 0.0719 | 0.0684 |
| $C_2$ | 1.1441 | 0.0000 | 0.0000 |
| $C_3$ | 0.0390 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.0020 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.0036 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0008 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0007 | 0.0000 | 0.0000 |
| $C_6$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 82.6200

Gross heating value of fuel gas = 37.53 $MJ/m^3$

= 887 MJ/kmole

(c) $NO_x$ Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.001091 \cdot 82.6200 \cdot 46.0055 \cdot 10^6}{100 \cdot 887}$$

$$= 46.8 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled turbine engines is 126 ng/J. The value obtained here is approximately 63% less than this EPA number.

2.2.3.5 Conclusions

The $NO_x$ emission factor for the tested turbine engine is 46.8 ng/J.

## 2.2.4 · Natural Gas Fueled Engines: $NO_x$ Test Report No. T-4

Test Date: January 8, 1986
Test Location: Princess Area
Tested By: R. Tamura & M. Towill

### 2.2.4.1 Summary

A 25 975 kW natural gas fueled turbine engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 72.9 ng/J was obtained. This is approximately 42% lower than the value of 126 ng/J (4700 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled turbine engines.

### 2.2.4.2 Introduction

See Report T-1 (i.e., Section 2.2.1.2).

### 2.2.4.3 Procedure

See Report T-1 (i.e., Section 2.2.1.3).

### 2.2.4.4 Results

(1) Basic Data:

Field Work

Date: January 8, 1986
Location: Princess Area
Test Crew: R. Tamura & M. Towill

Test Unit: Make - Pratt & Whittney
Model - FT-4C
Rated Power Level - 25 975 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 20°C
Barometric Pressure: 664.46 mm Hg
Relative Humidity: 36%

Lab Work

Date: January 13, 1986
Location: Calgary
Ambient Temperature: 20.0°C
Barometric Pressure: 671.83 mm Hg

(2) Gas Analysis:

Table 78. Flue gas composition: $NO_x$ test report No. T-4.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.9543 | 0.9528 | 0.9536 |
| $O_2$ | 16.8659 | 16.9388 | 16.9024 |
| $N_2$ | 79.7921 | 79.6646 | 79.7283 |
| $C_1$ | 0.0000 | 0.0000 | 0.0000 |
| CO | 0.0091 | 0.0095 | 0.0093 |
| $CO_2$ | 2.3714 | 2.4182 | 2.3948 |
| $C_2$ | 0.0000 | 0.0000 | 0.0000 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0072 | 0.0161 | 0.0116 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 79. Fuel gas composition: $NO_x$ test report No. T-4.

| Component | Mole Percent |
|---|---|
| $H_2$ | 0.0000 |
| Ar | 0.0000 |
| $O_2$ | 0.0000 |
| $N_2$ | 2.9818 |
| $C_1$ | 88.0874 |
| CO | 0.0000 |
| $CO_2$ | 1.1438 |
| $C_2$ | 6.0703 |
| $H_2S$ | 0.0000 |
| COS | 0.0000 |
| $C_3$ | 1.4882 |
| $SO_2$ | 0.0000 |
| $CS_2$ | 0.0000 |
| i-$C_4$ | 0.0405 |
| n-$C_4$ | 0.0583 |
| i-$C_5$ | 0.0280 |
| n-$C_5$ | 0.0226 |
| $C_6$ | 0.0791 |
| $C_7$+ | 0.0000 |
| | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.1849 $m^3$ |
| Meter Pressure - | 664.46 mm Hg |
| Meter Temperature - | 20.8°C |
| Impinger Pressure - | 591.44 mm Hg |
| Moles of Dried Flue Gas Metered - | 6.70 g - moles |
| Volume of $H_2O$ Condensed - | 6 ml |
| Moles of $H_2O$ Condensed - | 0.33 g - moles |
| Vapour Pressure of Drier - | 9.2100 mm Hg |
| Moles of $H_2O$ Vapour - | 0.11 g - moles |
| Total Moles of Wet Flue Gas - | 7.14 g - moles |
| $H_2O$ Concentration - | 6.14 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 80. $NO_x$ determination - field data: $NO_x$ test report No. T-4.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 18 | 13:15 | 30 | 2041.2 | 30.84 | 656.84 | 25 |
| 9 | 13:18 | 30 | 2038.4 | 25.76 | 654.30 | 25 |
| 2 | 13:20 | 30 | 2105.2 | 25.76 | 651.76 | 25 |
| 15 | 14:11 | 30 | 2027.3 | 23.22 | 656.84 | 25 |
| 5 | 14:13 | 30 | 2041.5 | 23.22 | 656.84 | 25 |
| 20 | 14:15 | 30 | 2079.9 | 20.68 | 641.60 | 25 |

(b) Lab Data:

Table 81. $NO_x$ determination - lab data: $NO_x$ test report No. T-4.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 18 | 697.23 | 20 | 33.96 |
| 9 | 699.77 | 20 | 31.88 |
| 2 | 695.96 | 20 | 33.49 |
| 15 | 691.64 | 20 | 6.11 |
| 5 | 702.31 | 20 | 28.13 |
| 20 | 720.09 | 20 | 29.58 |

Representative $NO_x$ Concentration*: 30.77 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 82. Overall gas compositions: $NO_x$ test report No. T-4.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 6.1400 |
| $NO_x$ | 0.0000 | 0.0000 | 0.0031 |
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.9536 | 0.8950 |
| $O_2$ | 0.0000 | 16.9024 | 15.8641 |
| $N_2$ | 2.9818 | 79.7283 | 74.8305 |
| CO | 0.0000 | 0.0093 | 0.0087 |
| $CO_2$ | 1.1438 | 2.3948 | 2.2477 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0116 | 0.0109 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 88.0874 | 0.0000 | 0.0000 |
| $C_2$ | 6.0703 | 0.0000 | 0.0000 |
| $C_3$ | 1.4882 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.0405 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.0583 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0280 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0226 | 0.0000 | 0.0000 |
| $C_6$ | 0.0791 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 47.4023

Gross heating value of fuel gas = 38.95 $MJ/m^3$

= 920 MJ/kmole

(c) $NO_x$ Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.003077 \cdot 47.4023 \cdot 46.0055 \cdot 10^6}{100 \cdot 920}$$

$$= 72.9 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled turbine engines is 126 ng/J. The value obtained here is approximately 42% less than this EPA number.

2.2.4.5 Conclusions

The $NO_x$ emission factor for the tested turbine engine is 72.9 ng/J.

## 2.2.5 Natural Gas Fueled Engines: $NO_x$ Test Report No. T-5

Test Date: January 8, 1986
Test Location: Hussar Area
Tested By: B. Reshetylo & T. Seedhouse

### 2.2.5.1 Summary

A 8690 kW natural gas fueled turbine engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 97.9 ng/J was obtained. This is approximately 22% lower than the value of 126 ng/J (4700 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled turbine engines.

### 2.2.5.2 Introduction

See Report T-1 (i.e., Section 2.2.1.2).

### 2.2.5.3 Procedure

See Report T-1 (i.e., Section 2.2.1.3).

### 2.2.5.4 Results

(1) Basic Data:

Field Work

Date: January 8, 1986
Location: Hussar Area
Test Crew: T. Seedhouse & B. Reshetylo

Test Unit: Make - Ingersol Rand
Model - JP-125
Rated Power Level - 8 690 kW
Service - Driver for a natural gas compressor

Ambient Temperature: 3°C
Barometric Pressure: 664.46 mm Hg
Relative Humidity: 36%

Lab Work

Date: January 13, 1986
Location: Calgary
Ambient Temperature: 20.0°C
Barometric Pressure: 671.83 mm Hg

(2) Gas Analysis:

Table 83. Flue gas composition: $NO_x$ test report No. T-5.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.9531 | 0.9545 | 0.9538 |
| $O_2$ | 17.2680 | 17.1713 | 17.2196 |
| $N_2$ | 79.6921 | 79.8046 | 79.7484 |
| $C_1$ | 0.0000 | 0.0000 | 0.0000 |
| CO | 0.0089 | 0.0084 | 0.0086 |
| $CO_2$ | 2.0779 | 2.0612 | 2.0696 |
| $C_2$ | 0.0000 | 0.0000 | 0.0000 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 84. Fuel gas composition: $NO_x$ test report No. T-5.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.0000 | 0.0000 |
| $O_2$ | 0.0000 | 0.0000 | 0.0000 |
| $N_2$ | 0.7704 | 0.9624 | 0.8664 |
| $C_1$ | 92.3799 | 92.2341 | 92.3070 |
| CO | 0.0000 | 0.0000 | 0.0000 |
| $CO_2$ | 0.5628 | 0.5616 | 0.5622 |
| $C_2$ | 4.8903 | 4.8604 | 4.8754 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.9682 | 0.9619 | 0.9650 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.1319 | 0.1321 | 0.1320 |
| n-$C_4$ | 0.2006 | 0.2020 | 0.2013 |
| i-$C_5$ | 0.0448 | 0.0462 | 0.0455 |
| n-$C_5$ | 0.0367 | 0.0353 | 0.0360 |
| $C_6$ | 0.0144 | 0.0040 | 0.0092 |
| | 100.0000 | 100.0000 | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.1699 $m^3$ |
| Meter Pressure - | 664.46 mm Hg |
| Meter Temperature - | 11.9°C |
| Impinger Pressure - | 613.66 mm Hg |
| Moles of Dried Flue Gas Metered - | 6.35 g - moles |
| Volume of $H_2O$ Condensed - | 4 ml |
| Moles of $H_2O$ Condensed - | 0.22 g - moles |
| Vapour Pressure of Drier - | 8.047 mm Hg |
| Moles of $H_2O$ Vapour - | 0.08 g - moles |
| Total Moles of Wet Flue Gas - | 6.66 g - moles |
| $H_2O$ Concentration - | 4.60 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 85. $NO_x$ determination - field data: $NO_x$ test report No. T-5.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 9A | 11:37 | 30 | 2038.40 | 49.78 | 664.46 | 0 |
| 23 | 11:41 | 30 | 1992.70 | 39.62 | 664.46 | 0 |
| 26 | 11:45 | 30 | 2020.00 | 37.08 | 667.00 | 0 |
| 22 | 12:25 | 30 | 2024.70 | 39.62 | 667.00 | 0 |
| 28 | 12:29 | 30 | 2001.00 | 44.70 | 664.46 | 0 |
| 27 | 12:33 | 30 | 2020.00 | 39.62 | 667.00 | 0 |

(b) Lab Data:

Table 86. $NO_x$ determination - lab data: $NO_x$ test report No. T-5.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 9A | Broken | 20.0 | - |
| 23 | 684.53 | 20.0 | 41.03 |
| 26 | 674.37 | 20.0 | 32.11 |
| 22 | 672.08 | 20.0 | 36.84 |
| 28 | 697.23 | 20.0 | 43.81 |
| 27 | 671.83 | 20.0 | 30.64 |

Representative $NO_x$ Concentration*: 36.66 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas both the high and low values were discarded and an average was taken of the remaining 3 readings.

(5) Detérmination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 87. Overall gas compositions: $NO_x$ test report No. T-5.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 0.0000 |
| $NO_x$ | 0.0000 | 0.0000 | 0.0000 |
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.9538 | 0.9099 |
| $O_2$ | 0.0000 | 17.2196 | 16.4269 |
| $N_2$ | 0.9664 | 79.7484 | 76.0770 |
| CO | 0.0000 | 0.0086 | 0.0082 |
| $CO_2$ | 0.5622 | 2.0696 | 1.9743 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 92.3070 | 0.0000 | 0.0000 |
| $C_2$ | 4.8754 | 0.0000 | 0.0000 |
| $C_3$ | 0.9650 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.1320 | 0.0000 | 0.0000 |
| n-$C_4$ | 0.2013 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.0455 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.0360 | 0.0000 | 0.0000 |
| $C_6$ | 0.0092 | 0.0000 | 0.0000 |
| $C_7$+ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 54.1284

Gross heating value of fuel gas = 39.4639 $MJ/m^3$

= 932 MJ/kmole

(c) $NO_x$ Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.003666 \cdot 54.1284 \cdot 46.0055 \cdot 10^6}{100 \cdot 932}$$

$$= 97.9 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled turbine engines is 126 ng/J. The value obtained here is approximately 22% less than this EPA number.

2.2.5.5 Conclusions

The $NO_x$ emission factor for the tested turbine engine is 97.9 ng/J.

## 2.2.6 · Natural Gas Fueled Engines: $NO_x$ Test Report No. T-6

Test Date: January 13, 1986
Test Location: Harmatten Area
Tested By: T. Seedhouse & C. Scott

### 2.2.6.1 Summary

A 2 650 kW natural gas fueled turbine engine was tested to determine its effective oxides of nitrogen ($NO_x$) emission factor under field conditions (i.e., equivalent ng of $NO_2$ emitted per J of fuel consumed). A value of 175.7 ng/J was obtained. This is approximately 39% higher than the value of 126 ng/J (4700 kg/$10^6$ $Nm^3$ of natural gas fuel) which has been presented by the U.S. Environmental Protection Agency for typical industrial natural gas fueled reciprocating engines.

### 2.2.6.2 Introduction

See Report T-1 (i.e., Section 2.2.1.2).

### 2.2.6.3 Procedure

See Report T-1 (i.e., Section 2.2.1.3).

### 2.2.6.4 Results

(1) Basic Data:

Field Work

Date: January 13, 1986
Location: Harmatten Area
Test Crew: T. Seedhouse & C. Scott

Test Unit: Make - Solar - Centaur
Model - 1970
Rated Power Level - 2 650 kW
Service - Driver for a water injection pump

Ambient Temperature: 12°C
Barometric Pressure: 671.83 mm Hg
Relative Humidity: 26%

Lab Work

Date: January 14, 1986
Location: Calgary
Ambient Temperature: 21.5°C
Barometric Pressure: 668.20 mm Hg

(2) Gas Analysis:

Table 88. Flue gas composition: $NO_x$ test report No. T-6.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.1425 | 0.1446 | 0.1435 |
| Ar | 0.9485 | 0.9506 | 0.9496 |
| $O_2$ | 17.3612 | 17.1638 | 17.2625 |
| $N_2$ | 79.3064 | 79.4805 | 79.3935 |
| $C_1$ | 0.0000 | 0.0000 | 0.0000 |
| CO | 0.0035 | 0.0031 | 0.0033 |
| $CO_2$ | 2.2379 | 2.2573 | 2.2476 |
| $C_2$ | 0.0000 | 0.0000 | 0.0000 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 0.0000 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

Table 89. Fuel gas composition: $NO_x$ test report No. T-6.

| Component | Mole Percent Sample 1 | Sample 2 | Average |
|---|---|---|---|
| $H_2$ | 0.0000 | 0.0000 | 0.0000 |
| Ar | 0.0000 | 0.0000 | 0.0000 |
| $O_2$ | 0.0000 | 0.0000 | 0.0000 |
| $N_2$ | 0.6205 | 0.6176 | 0.6190 |
| $C_1$ | 73.3170 | 73.1878 | 73.2524 |
| CO | 0.0000 | 0.0000 | 0.0000 |
| $CO_2$ | 5.1923 | 5.2936 | 5.2430 |
| $C_2$ | 11.9224 | 12.0193 | 11.9708 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $C_3$ | 5.2839 | 5.3557 | 5.3198 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.8764 | 0.8791 | 0.8778 |
| n-$C_4$ | 1.7206 | 1.6847 | 1.7027 |
| i-$C_5$ | 0.3648 | 0.3493 | 0.3570 |
| n-$C_5$ | 0.3958 | 0.3647 | 0.3802 |
| $C_6$ | 0.2694 | 0.2198 | 0.2446 |
| $C_7$+ | 0.0369 | 0.0284 | 0.0327 |
| | 100.0000 | 100.0000 | 100.0000 |

(3) Flue Gas Moisture Content

| | |
|---|---|
| Volume of Flue Gas Metered - | 0.1727 $m^3$ |
| Meter Pressure - | 671.83 mm Hg |
| Meter Temperature - | 13.9°C |
| Impinger Pressure - | 608.33 mm Hg |
| Moles of Dried Flue Gas Metered - | 6.48 g - moles |
| Volume of $H_2O$ Condensed - | 1 ml |
| Moles of $H_2O$ Condensed - | 0.06 g - moles |
| Vapour Pressure of Drier - | 8.905 mm Hg |
| Moles of $H_2O$ Vapour - | 0.10 g - moles |
| Total Moles of Wet Flue Gas - | 6.63 g - moles |
| $H_2O$ Concentration - | 2.29 mole percent |

(4) Flue Gas $NO_x$ Content

(a) Field Data

Table 90. $NO_x$ determination - field data: $NO_x$ test report No. 1-6.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 2 | 12:40 | 30 | 2105.2 | 57.15 | 671.83 | 10 |
| 18 | 12:43 | 30 | 2041.2 | 49.53 | 671.83 | 10 |
| 9 | 12:46 | 30 | 2038.4 | 54.61 | 671.83 | 10 |
| 15 | 13:35 | 30 | 2027.3 | 50.80 | 671.83 | 10 |
| 20 | 13:38 | 30 | 2079.9 | 44.45 | 671.83 | 10 |
| 5 | 13:41 | 30 | 2041.5 | 45.72 | 669.29 | 10 |

(b) Lab Data:

Table 91. $NO_x$ determination - lab data: $NO_x$ test report No. T-6.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$ Concentration* (ppm) |
|---|---|---|---|
| 2 | 673.28 | 21.5 | 61.91 |
| 18 | 670.74 | 21.5 | 75.30 |
| 9 | 673.28 | 21.5 | 69.48 |
| 15 | 670.74 | 21.5 | 61.12 |
| 20 | 673.28 | 21.5 | 74.06 |
| 5 | 670.74 | 21.5 | 62.46 |

Representative $NO_x$ Concentration**: 66.98 ppm

* On a wet basis.

** To obtain a single representative $NO_x$ concentration for the flue gas, both the high and low values were discarded and an average was taken of the remaining 4 readings.

(5) Determination of $NO_x$ Emission Factor

(a) Overall Gas Compositions

Table 92. Overall gas compositions: $NO_x$ test report No. T-6.

| Component | Composition (mole percent) | | |
|---|---|---|---|
| | Fuel Gas | $H_2O$ & $NO_x$ Free Flue Gas | Flue Gas |
| $H_2O$ | 0.0000 | 0.0000 | 2.2900 |
| $NO_x$ | 0.0000 | 0.0000 | 0.0067 |
| $H_2$ | 0.0000 | 0.1435 | 0.1402 |
| Ar | 0.0000 | 0.9496 | 0.9278 |
| $O_2$ | 0.0000 | 17.2625 | 16.8660 |
| $N_2$ | 0.6190 | 79.3935 | 77.5701 |
| CO | 0.0000 | 0.0033 | 0.0032 |
| $CO_2$ | 5.2430 | 2.2476 | 2.1960 |
| $H_2S$ | 0.0000 | 0.0000 | 0.0000 |
| COS | 0.0000 | 0.0000 | 0.0000 |
| $SO_2$ | 0.0000 | 0.0000 | 0.0000 |
| $CS_2$ | 0.0000 | 0.0000 | 0.0000 |
| $C_1$ | 73.2524 | 0.0000 | 0.0000 |
| $C_2$ | 11.9708 | 0.0000 | 0.0000 |
| $C_3$ | 5.3198 | 0.0000 | 0.0000 |
| i-$C_4$ | 0.8778 | 0.0000 | 0.0000 |
| n-$C_4$ | 1.7027 | 0.0000 | 0.0000 |
| i-$C_5$ | 0.3570 | 0.0000 | 0.0000 |
| n-$C_5$ | 0.3802 | 0.0000 | 0.0000 |
| $C_6$ | 0.2446 | 0.0000 | 0.0000 |
| $C_7$+ | 0.0327 | 0.0000 | 0.0000 |
| | 100.0000 | 100.0000 | 100.0000 |

(b) Other Information:

Stoichiometric Coefficient "b" = 60.0770

Gross heating value of fuel gas = 45.26 $MJ/m^3$
= 1070 MJ/kmole

(c) $NO_x$ Emission Factor

Using equation (2), the $NO_x$ emission factor is given by:

$$EF = \frac{0.006698 \cdot 60.0770 \cdot 46.0055 \cdot 10^6}{100 \cdot 1070}$$

$$= 175.7 \text{ ng/J}$$

The $NO_x$ emission factor presented by the U.S. Environmental Protection Agency (EPA) for industrial natural gas fueled turbine engines is 126 ng/J. The value obtained here is approximately 39% higher than this EPA number.

2.2.6.5 Conclusions

The $NO_x$ emission factor for the tested turbine engine is 175.7 ng/J.

## 2.3 INDIVIDUAL REPORTS FOR THE SURVEYED WASTE GAS INCINERATOR UNITS

The individual reports prepared for each of the three waste gas incinerator units surveyed are presented in the following. Since the Introduction and Procedure sections of each report are basically the same, these have been omitted from all but the first report to avoid repetition.

## 2.3.1 Incinerator Stacks: $NO_x$ Test Report I-1

### 2.3.1.1 Summary

The incinerator stack for a small sulphur recovery unit (roughly 10 tonnes/day capacity) has been analyzed for NOx emissions. The determined rate of $NO_x$ emissions was 0.0198 t/d* or 120.2 x $10^{-6}$ $m^3/s$**. An $NO_x$ emission rate of this magnitude is not considered to be a noteworthy source of atmospheric pollution.

The average mass ratio of $NO_x/SO_x$ emitted from the stack was 0.00347. Therefore, in comparison to $SO_x$ emissions, the $NO_x$ emissions are insignificant.

### 2.3.1.2 Introduction

A major application for incinerators in Alberta is the incineration of toxic tail gases from sulphur recovery units. Incinerators of this type are noteworthy sources of oxides of sulphur ($SO_x$) emissions. However, it is not clear whether they are also significant sources of $NO_x$. To determine the significance of the $NO_x$ emissions, the results of tests conducted on the incinerator stacks from small, medium and large sulphur recovery units (i.e., in the order of 10, 100 and 1000 tonnes of sulphur per day, respectively) were examined.

This report discusses $NO_x$ testing conducted at a small sulphur recovery unit.

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* All $NO_x$ emissions have been expressed as an $NO_2$ equivalent.

** At base conditions of 21.1°C and 101.325 kPa.

2.3.1.3 Procedure

(1) The following basic data were recorded:

- date,
- location,
- test crew,
- relative humidity,
- ambient temperature,
- barometric pressure, and
- plant size.

(2) The concentration of $NO_x$ in the stack gases was determined using the $NO_x$ test procedure described under Method 6 in the Alberta Environment Stack Sampling Code. Six NOx samples were collected.

(3) The $NO_x$ testing was conducted in conjunction with a regularly scheduled $SO_x$ compliance test. This $SO_x$ compliance test consisted of triplicate tests for determination of:

- gas velocity,
- volumetric flow rate,
- moisture content,
- gas composition (gas chromatograph analysis), and
- $SO_x$ emissions.

Each of these tests, with the exception of that for $SO_x$, was conducted in accordance with the Alberta Environment Stack Sampling Code (1976).

$SO_x$ emissions (i.e., the sum of $SO_2$ and $SO_3$ emissions) were determined using a modification of Alberta Environment (AE) Method 5 for determination of $SO_2$ emissions (1976). AE Method 5 requires that a distinction be made between $SO_2$ and $SO_3$ emissions. This is achieved through the use of two quantitative

absorption processes - first the sample is reacted with isopropanol for preferential removal of $SO_3$ and then it is reacted with and aqueous $H_2O_2$ solution for removal of the $SO_2$. Since a distinction between $SO_2$ and $SO_3$ emissions is not required here, the isopropanol solution was omitted and the $SO_2$ and $SO_3$ reacted simultaneously using the $H_2O_2$ solution to obtain total $SO_x$. The result of this modification is a simplified method for determination of $SO_x$ emissions. This modified method is accepted by Alberta Environment for use in routine compliance tests.

(4) The volumetric emission rate of $NO_x$ at standard conditions (i.e., 101.325 kPa and 21.1°C), was determined using equation (1) below,

$$ER_V = C\ (NOx) \cdot Qs \cdot 10^{-6} \qquad (1)$$

where, $ER_V$ = volumetric rate of NOx emission, $m^3/s$

Qs = average volumetric flow rate of flue gases expressed at standard conditions (determined in (3)), $m^3/s$.

$C\ (NO_x)$ = the average concentration of $NO_x$ (determined in (2)), ppm.

(5) The mass rate of $NO_x$ emissions was determined using equation (2) below,

$$ER_M = 164.6 \cdot ER_V \qquad (2)$$

where, $ER_M$ = mass rate of $NO_x$ emission, t/d.

(6) The mass ratio of $NO_x$ to $SO_x$ was determined using equation (3) below,

$$MR(NO_x/SO_x) = \frac{C(NO_x) \cdot M(NO_x) \cdot 10^{-4}}{C(SO_x) \cdot M(SO_x)}$$

where, $MR(NO_x/SO_x)$ = the mass ratio of $NOx/SO_x$.
$C(SO_x)$ = average concentration of $SO_x$, mole percent.
$M(SO_x)$ = molecular weight of $SO_x$ expressed as an $SO_2$ equivalent (i.e., 64.059 kg/mole).
$M(NO_x)$ = molecular weight of $NO_x$ expressed in terms of $NO_2$ (i.e., 46.006 kg/kmole).

2.3.1.4 Results

(1) Basic Data:

Field Work

Date: September 16, 1985
Location: North of Calgary
Test Crew: B. Reshetylo & C. Scott

Ambient Temperature: 15°C
Barometric Pressure: 661.1 mm Hg
Relative Humidity: 27%

Lab Work

Date: September 17, 1985
Location: Calgary
Ambient Temperature: 24°C
Barometric Pressure: 666.2 mm Hg

(2) Determination of $NO_x$ Concentration

Table 93. $NO_x$ determination - field data: $NO_x$ test report No. I-1.

| Flask Number | Time | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 2 | 12:05 | 30 | 2105.2 | 41.3 | 656.0 | 15 |
| 15 | 12:10 | 30 | 2027.3 | 38.8 | 661.1 | 15 |
| 5 | 13:05 | 30 | 2041.5 | 46.4 | 658.6 | 15 |
| 18 | 13:10 | 30 | 2041.2 | 46.4 | 661.1 | 15 |
| 12 | 13:55 | 30 | 2032.0 | 51.5 | 661.1 | 15 |
| 32 | 14:00 | 30 | 2004.0 | 46.7 | 661.1 | 15 |

Table 94. $NO_x$ determination - lab data: $NO_x$ test report No. I-1.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent NOx* Concentration (ppm) |
|---|---|---|---|
| 2 | 667.5 | 24 | 21.69 |
| 15 | 668.7 | 24 | 31.79 |
| 5 | 663.7 | 24 | 35.84 |
| 18 | 666.2 | 24 | 49.06 |
| 12 | 666.2 | 24 | 26.16 |
| 32 | 663.7 | 24 | 14.97 |

* On a wet basis.

(3) $SO_x$ Stack Survey

Table 95. $SO_x$ stack survey results: $NO_x$ test report No. I-1.

| Parameter | Test One | Test Two | Test Three | Average |
|---|---|---|---|---|
| Test Period | 11:13-12:13 | 12:16-13:16 | 13:18-14:18 | |
| Measured Average Temp. of Flue Gas at Sampling Level - °C | 615 | 620 | 612 | 616 |
| Measured Average Velocity of Flue Gas at Sampling Level - m/s | 13.833 | 13.534 | 13.357 | 13.575 |
| Calculated Average Velocity of Flue Gas at Stack Exit - m/s | 13.833 | 13.534 | 13.357 | 13.575 |
| Total Flue Gas Flow Rate* | | | | |
| - $m^3/s$ | 4.248 | 4.132 | 4.116 | 4.165 |
| - $dam^3/d$ | 367.027 | 357.005 | 355.622 | 359.885 |
| Average $H_2O$ Content of Flue Gas - mole percent | 17.06 | 22.13 | 21.72 | 20.30 |
| OXIDES OF SULPHUR | | | | |
| Concentration - mole percent | 0.5860 | 0.5861 | 0.6224 | 0.5932 |
| Flow Rate* - $m^3/s$ | 0.025 | 0.024 | 0.026 | 0.025 |
| Emission as $SO_2$ - t/d | 5.712 | 5.556 | 5.878 | 5.716 |
| as S - t/d | 2.856 | 2.778 | 2.939 | 2.858 |
| Total Reduced Sulphur - ppm, wet | N.D. | N.D. | N.D. | N.D. |

N.D. - None detected.
* At 21.1°C and 101.325 kPa.

(4) $NO_X$ Emissions

Table 96. Summary of $NO_X$ emission testing: $NO_X$ test report No. I-1.

| | |
|---|---|
| Average $NO_X$ Concentration (ppm) | 28.87 |
| $NO_X$ Emission Rate | |
| - Volumetric* ($m^3/s$) | $120.2 \times 10^{-6}$ |
| - Mass (t/d)** | 0.0198 |
| $NO_X/SO_2$ Mass Ratio | 0.00347 |

* At 21.1°C and 101.325 kPa
** Expressed as an $NO_2$ equivalent

The average $NO_X$ concentration of 28.87 ppm shown in Table 96 was obtained by discarding the high and low sample values shown in Table 2, and taking the average of the 4 remaining samples. The volumetric and mass emission rates, $120.2 \times 10^{-6}$ $m^3/s$ and 0.0198 t/d, were then calculated using equations (1) and (2), respectively. An $NO_X$ emission rate of this magnitude is roughly that which a 60 kW natural gas fueled reciprocating engine might produce under full load. Based on these results, the incinerator is a relatively insignificant source of $NO_X$ emissions. Furthermore, with an $NO_X/SO_2$ mass ratio of 0.00347 (calculated using equation (3)), the $NO_X$ emissions are insignificant in comparison to the $SO_2$ emissions.

2.3.1.5 Conclusion

The tested incinerator stack is not a noteworthy source of $NO_X$ emissions.

## 2.3.2 Incinerator Stacks: $NO_x$ Test Report I-2

### 2.3.2.1 Summary

The incinerator stack for a small sulphur recovery unit (roughly 170 tonnes/day capacity) has been analyzed for $NO_x$ emissions. The determined rate of $NO_x$ emissions was 0.0093 t/d* or 56.4 x $10^{-6}$ $m^3/s$**. An $NO_x$ emission rate of this magnitude is not considered to be a noteworthy source of atmospheric pollution.

The average mass ratio of $NO_x/SO_2$ emitted from the stack was 0.00189. Therefore, in comparison to $SO_2$ emissions, the $NO_x$ emissions are insignificant.

### 2.3.2.2 Introduction

See Report I-1 (i.e., Section 2.3.1.2).

### 2.3.2.3 Procedure

See Report I-1 (i.e., Section 2.3.1.3).

---

* All $NO_x$ emissions have been expressed as an $NO_2$ equivalent.

** At base conditions of 21.1°C and 101.325 kPa.

2.3.2.4 Results

(1) Basic Data:

Field Work

Date: October 22, 1985
Location: Northwest of Edmonton
Test Crew: B. Reshetylo & D. Picard

Ambient Temperature: 5°C
Barometric Pressure: 666.5 mm Hg
Relative Humidity: 40%

Lab Work

Date: October 27, 1985
Location: Calgary
Ambient Temperature: 21°C
Barometric Pressure: 663.5 mm Hg

(2) Determination of $NO_x$ Concentration

Table 97. $NO_x$ determination - field data: $NO_x$ test report No. I-2.

| Flask Number | Test Number | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 17 | 10:38 | 30 | 2102.8 | 51.82 | 661.42 | 10 |
| 34 | 10:40 | 30 | 2003.00 | 59.44 | 658.88 | 10 |
| 30 | 10:43 | 30 | 2010.00 | 56.90 | 666.50 | 10 |
| 35 | 12:09 | 30 | 2002.00 | 64.52 | 656.34 | 10 |
| 3A | 12:11 | 30 | 2054.30 | 64.52 | 646.18 | 10 |
| 32 | 12:18 | 30 | 2004.00 | 61.98 | 656.34 | 10 |

Table 98. $NO_x$ determination - lab data: $NO_x$ test report No. I-2.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent NOx* Concentration (ppm) |
|---|---|---|---|
| 17 | 676.25 | 21 | 8.03 |
| 34 | 673.66 | 21 | 4.78 |
| 30 | 668.58 | 21 | 8.23 |
| 35 | 671.12 | 21 | 13.24 |
| 3A | 658.42 | 21 | 15.30 |
| 32 | 676.2 | 21 | 7.19 |

* On a wet basis.

(3) $SO_2$ Stack Survey

Table 99. $SO_x$ stack survey results: $NO_x$ test report No. I-2.

| Parameter | Test One | Test Two | Test Three | Average |
|---|---|---|---|---|
| Test Period | 09:12-10:12 | 10:22-11:22 | 11:30-12:30 | |
| Measured Average Temp. of Flue Gas at Sampling Level - °C | 623 | 627 | 625 | 625 |
| Measured Average Velocity of Flue Gas at Sampling Level - m/s | 14.660 | 14.924 | 14.187 | 14.590 |
| Calculated Average Velocity of Flue Gas at Stack Exit - m/s | 32.986 | 33.580 | 31.922 | 32.829 |
| Total Flue Gas Flow Rate* | | | | |
| - $m^3/s$ | 6.196 | 6.280 | 5.980 | 6.152 |
| - $dam^3/d$ | 535.334 | 542.592 | 516.672 | 531.533 |
| Average $H_2O$ Content of Flue Gas - mole percent | 20.23 | 20.70 | 20.70 | 20.54 |
| OXIDES OF SULPHUR | | | | |
| Concentration - mole percent | 0.3364 | 0.3520 | 0.3576 | 0.3487 |
| Flow Rate* - $m^3/s$ | 0.021 | 0.022 | 0.021 | 0.021 |
| Emission as $SO_2$ - t/d | 4.782 | 5.072 | 4.906 | 4.920 |
| as S - t/d | 2.391 | 2.536 | 2.453 | 2.460 |
| Total Reduced Sulphur - ppm, wet | N.D. | N.D. | N.D. | N.D. |

N.D. - None detected.
* At 21.1°C and 101.325 kPa.

(4) NOx Emissions

Table 100. Summary of $NO_X$ emission testing: $NO_X$ test report No. I-2.

| | |
|---|---|
| Average $NO_X$ Concentration (ppm) | 9.17 |
| $NO_X$ Emission Rate | |
| - Volumetric* ($m^3/s$) | $56.4 \times 10^{-6}$ |
| - Mass (t/d)** | 0.0093 |
| $NO_X/SO_2$ Mass Ratio | 0.00189 |

* At 21.1°C and 101.325 kPa
** Expressed as an $NO_2$ equivalent

The average $NO_X$ concentration of 9.17 ppm, shown in Table 100, was obtained by discarding the high and low sample values shown in Table 2, and taking the average of the 95 remaining samples. The volumetric and mass emission rates, $56.4 \times 10^{-6}$ $m^3/s$ and 0.0093 t/d, were then calculated using equations (1) and (2), respectively. An $NO_X$ emission rate of this magnitude is roughly that which a 30 kW natural gas fueled reciprocating engine might produce under full load. Based on these results, the incinerator is a relatively insignificant source of $NO_X$ emissions. Furthermore, with an $NO_X/SO_2$ mass ratio of 0.00189 (calculated using equation (3)), the $NO_X$ emissions are insignificant in comparison to the $SO_2$ emissions.

2.3.2.5 Conclusion

The tested incinerator stack is not a noteworthy source of $NO_X$ emissions.

## 2.3.3 Incinerator Stacks: $NO_x$ Test Report I-3

### 2.3.3.1 Summary

The incinerator stack for a large sulphur recovery unit (roughly 1200 tonnes/day capacity) has been analyzed for $NO_x$ emissions. The determined rate of $NO_x$ emissions was 0.0337 t/d* or 204.9 x $10^{-6}$ $m^3/s$**. An $NO_x$ emission rate of this magnitude is not considered to be a noteworthy source of atmospheric pollution.

The average mass ratio of $NO_x/SO_2$ emitted from the stack was 0.00108. Therefore, in comparison to $SO_2$ emissions, the $NO_x$ emissions are insignificant.

### 2.3.3.2 Introduction

See Report I-1 (i.e., Section 2.3.1.2).

### 2.3.3.3 Procedure

See Report I-1 (i.e., Section 2.3.1.3).

---

* All $NO_x$ emissions have been expressed as an $NO_2$ equivalent.
** At base conditions of 21.1°C and 101.325 kPa.

2.3.3.4 Results

(1) Basic Data:

Field Work

Date: December 12, 1985
Location: Northwest of Edmonton
Test Crew: B. Reshetylo & T. Seedhouse

Ambient Temperature: -22°C
Barometric Pressure: 695.45 mm Hg
Relative Humidity: 98%

Lab Work

Date: December 16, 1985
Location: Calgary
Ambient Temperature: 23°C
Barometric Pressure: 703.33 mm Hg

(2) Determination of $NO_x$ Concentration

Table 101. $NO_x$ determination - field data: $NO_x$ test report No. I-3.

| Flask Number | Test Number | Volume (ml) | | Flask Pressure (mm Hg) | | Flask Temperature (°C) |
|---|---|---|---|---|---|---|
| | | Absorbing Solution | Flask | Evacuated | Filled | |
| 23 | 12:37 | 30 | 1992.7 | 78.23 | 695.45 | -10 |
| 22 | 12:36 | 30 | 2024.7 | 60.45 | 695.45 | -10 |
| 9A | 13:35 | 30 | 2038.4 | 73.15 | 697.99 | -10 |
| 28 | 13:38 | 30 | 2001.0 | 73.15 | 695.45 | -10 |
| 27 | 14:49 | 30 | 2020.0 | 85.85 | 695.45 | -10 |
| 26 | 14:55 | 30 | 2020.0 | 73.15 | 695.45 | -10 |

Table 102. $NO_x$ determination - lab data: $NO_x$ test report No. I-3.

| Flask Number | Flask Pressure (mm Hg) | Flask Temperature (°C) | Equivalent $NO_x$* Concentration (ppm) |
|---|---|---|---|
| 23 | 776.99 | 23 | 3.10 |
| 22 | 703.33 | 23 | 7.56 |
| 9A | 703.33 | 23 | 4.05 |
| 28 | 703.33 | 23 | 4.61 |
| 27 | 703.33 | 23 | 4.21 |
| 26 | 703.33 | 23 | 1.69 |

* On a wet basis.

(3) $SO_2$ Stack Survey

Table 103. $SO_x$ stack survey results: $NO_x$ test report No. I-3.

| Parameter | Test One | Test Two | Test Three | Average |
|---|---|---|---|---|
| Test Period | 11:25-12:25 | 12:40-13:40 | 13:48-14:48 | |
| Measured Average Temp. of Flue Gas at Sampling Level - °C | 400 | 401 | 403 | 401 |
| Measured Average Velocity of Flue Gas at Sampling Level - m/s | 13.890 | 13.885 | 13.485 | 13.753 |
| Calculated Average Velocity of Flue Gas at Stack Exit - m/s | 13.890 | 13.885 | 13.485 | 13.753 |
| Total Flue Gas Flow Rate* | | | | |
| - $m^3/s$ | 51.956 | 51.842 | 50.159 | 51.319 |
| - $dam^3/d$ | 4488.998 | 4479.149 | 4333.738 | 4433.96 |
| Average $H_2O$ Content of Flue Gas - mole percent | 21.21 | 21.78 | 21.34 | 21.44 |
| OXIDES OF SULPHUR | | | | |
| Concentration - mole percent | 0.2641 | 0.2724 | 0.2568 | 0.2644 |
| Flow Rate* - $m^3/s$ | 0.137 | 0.14 | 0.129 | 0.136 |
| Emission as $SO_2$ - t/d | 31.486 | 32.404 | 29.556 | 31.148 |
| as S - t/d | 15.743 | 16.202 | 14.778 | 15.574 |
| Total Reduced Sulphur - ppm, wet | N.D. | N.D. | N.D. | N.D. |

N.D. - None detected.
* At 21.1°C and 101.325 kPa.

(4) NOx Emissions

Table 104. Summary of NOx emission testing: $NO_X$ test report No. I-3.

| | |
|---|---|
| Average $NO_X$ Concentration (ppm) | 3.99 |
| $NO_X$ Emission Rate | |
| - Volumetric* ($m^3/s$) | $204.9 \times 10^{-6}$ |
| - Mass (t/d)** | 0.0337 |
| $NO_X/SO_2$ Mass Ratio | 0.00108 |

* At 21.1°C and 101.325 kPa
** Expressed as an $NO_2$ equivalent

The average $NO_X$ concentration of 3.99 ppm shown in Table 104 was obtained by discarding the high and low sample values shown in Table 2, and taking the average of the 4 remaining samples. The volumetric and mass emission rates, $204.9 \times 10^{-6}$ $m^3/s$ and 0.0337 t/d, were then calculated using equations (1) and (2), respectively. An $NO_X$ emission rate of this magnitude is roughly that which a 100 kW natural gas fueled reciprocating engine might produce under full load. Based on these results, the incinerator is a relatively insignificant source of $NO_X$ emissions. Furthermore, with an $NO_X/SO_2$ mass ratio of 0.00108 (calculated using equation (3)), the $NO_X$ emissions are insignificant in comparison to the $SO_2$ emissions.

2.3.3.5 Conclusion

The tested incinerator stack is not a noteworthy source of $NO_X$ emissions.

## 3. REFERENCES CITED

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